

Nebraska Water Center Annual Technical Report FY 2016

Introduction

Dr. Chittaranjan Ray, Ph.D., P.E., professor in the University of Nebraska-Lincoln's Department of Civil Engineering, became director of the Nebraska Water Center on August 1, 2013. Steve Ress and Tricia Liedle respectively serve as communications coordinator and program specialist. During the past year, Ben Beckman was hired jointly by the NWC, Daugherty Water for Food Global Institute and Nebraska Extension as a full-time outreach and education coordinator. Serving part-time as NWC staff are Rachael Herpel, as legislative liaison and outreach coordinator; and Craig Eiting, as web developer and desktop publisher. NWC became part of the Daugherty Global Institute in 2012, when its name was changed from the previous University of Nebraska-Lincoln (or UNL) Water Center.

The Nebraska Water Center is currently officed within the Daugherty Water for Food Global Institute at the new Nebraska Innovation Campus, at 2021 Transformation Dr., Ste. 3220, Lincoln, NE 68588-6204 U.S.A.

The Nebraska Water Center was the lead organizer for several events in 2017: (1) Basin-specific panels looked at state water management and state and local water law were featured in back-to-back one-day water symposium and water law conference in October at Nebraska Innovation Campus. The event was partially sponsored by the USGS Nebraska Water Science Center; (2) the 45th annual water and natural resources tour visited the Platte River basin in Colorado for three days in June, focusing primarily on increasing urban water needs in the Denver-metro area and its ultimate effect on down stream flows to Nebraska; (3) a series of seven free, public lectures themed to "The right water for the right use at the right time" constituted the annual spring semester water seminar series, which the Nebraska Water Center co-hosts with the University of Nebraska-Lincoln's School of Natural Resources. More than a dozen undergraduate students enrolled in the seminar for 1-hour of course credit in addition to public attendance at the lectures; (4) In September, water researchers from around the world gathered in Lincoln for a three-day "Virtual Water in Agricultural Products: Quantification, Limitations and Trade Policy" workshop with financial support coming from the Organization Economic Cooperation and Development (OECD) as well as the Nebraska Water Center, Daugherty Water for Food Global Institute and UNL's Institute of Agriculture and Natural Resources. The international workshop was among the first of its kind at the University of Nebraska-Lincoln.

Research Program Introduction

For the 2016 fiscal year, three research seed grants received funding through the USGS 104(b) program. These were: (1) Design of Multi-Scale Soil Moisture Monitoring Networks in Agricultural Systems Using Hydrogeophysics; and (2) Fate of Manure-Borne Antimicrobials Monensin, Lincomycin, and Sulfamethazine and Potential Effects to Nitrogen Transformation in Soil; and (3) Climate Variability and Decision Support Tool for Optimizing Yields with Limited Water Available for Irrigation; and (4) Development of Smart Alginate Hybrid Beads for Eco-Friendly Water Treatment.

Seed grants chosen for the upcoming year 2017 are: (1) Evaluation of Changing Irrigation Management on Ground Water Recharge and Quality; (2) Water Usage in the Food Industry; and (3) Economic, Environmental, and Crop Performance Assessment Under Center Pivot, Subsurface Drip, and Furrow Irrigation Systems in a Changing Climate in West Central Nebraska.

The Nebraska Water Sciences Laboratory (WSL) is a core research facility that is part of the Nebraska Water Center. Established in 1990, the WSL is a state-of-the-art research and teaching laboratory designed to provide technical services and expertise in analytical and isotopic methods. The facility provides specialized instrumentation and methods for organic, emerging contaminants, heavy metals, and for stable isotope mass spectrometry. It's mission extends to being a methodology development and teaching facility for both faculty and students. Faculty, staff, and students have analyzed thousands of samples at the facility.

Nitrate Mediated Mobilization of Naturally Occurring Uranium in Groundwater

Basic Information

Title:	Nitrate Mediated Mobilization of Naturally Occurring Uranium in Groundwater
Project Number:	2014NE265G
USGS Grant Number:	
Start Date:	9/1/2014
End Date:	8/31/2017
Funding Source:	104G
Congressional District:	
Research Category:	Water Quality
Focus Categories:	Hydrogeochemistry, Nitrate Contamination, Radioactive Substances
Descriptors:	None
Principal Investigators:	Karrie Anne Weber, Daniel Davidson Snow

Publications

1. Nolan, Jason; Karrie A. Weber, 2015. Natural Uranium Contamination in Major U.S. Aquifers Linked to Nitrate. Environmental Science & Technology Letters, 2 (8), 215-220.
2. Weber, Karrie A.; Olivia Healy; Jason Nolan; Don Pan; Kate Campbell; Abbey Heithoff; Trisha Spanbauer; Daniel Snow, Nitrate stimulated uranium mobilization in groundwater. in preparation.
3. Nolan, Jason P.; Sharon Bone; Kate Campbell; Don Pan; Olivia Healy; Chris Elofson; Robert M. Joeckel; Marty Stange; Todd Wilson; Paul Hanson, John Bargar; Daniel Snow; Karrie A. Weber, Naturally Occurring Uranium in an Oxidic Alluvial Aquifer. in preparation.
4. Nolan, Jason P., Don Pan, Olivia Healy, Marty Stange, Karrie A. Weber. Geogenic Aqueous Uranium in an Alluvial Aquifer. Goldschmidt. August 16-21, 2015. Prague, Czech Republic. (poster presentation)
5. Nolan, Jason; Karrie A. Weber, 2015. Natural Uranium Contamination in Major U.S. Aquifers Linked to Nitrate. Environmental Science & Technology Letters, 2 (8), 215-220.
6. Weber, Karrie A.; Olivia Healy; Jason Nolan; Don Pan; Kate Campbell; Abbey Heithoff; Trisha Spanbauer; Daniel Snow, Nitrate stimulated uranium mobilization in groundwater. in preparation.
7. Nolan, Jason P.; Sharon Bone; Kate Campbell; Don Pan; Olivia Healy; Chris Elofson; Robert M. Joeckel; Marty Stange; Todd Wilson; Paul Hanson, John Bargar; Daniel Snow; Karrie A. Weber, Naturally Occurring Uranium in an Oxidic Alluvial Aquifer. in preparation.
8. Nolan, Jason P., Don Pan, Olivia Healy, Marty Stange, Karrie A. Weber. Geogenic Aqueous Uranium in an Alluvial Aquifer. Goldschmidt. August 16-21, 2015. Prague, Czech Republic. (poster presentation)
9. Nolan, Jason P. Mobilization of Naturally Occurring Uranium in Sediment Into Groundwater (Dissertation). University of Nebraska, Lincoln.
10. Weber, K.A. Uranium and Nitrate in Groundwater. Nebraska Natural Resource District Conference, Kearney, NE, March 1, 2016.
11. Weber, K. A. Keynote. Life Beneath Our Feet: Influence on Water Quality. Iowa State University. Environmental Science Graduate Research Symposium. April 1, 2016.
12. Weber, K.A. Nitrate and Uranium in Groundwater, NRD Annual Conference, Kearney, NE, March 1, 2016.

Nitrate Mediated Mobilization of Naturally Occurring Uranium in Groundwater

13. Westrop, J., Nolan, J.P. , Pan, D. , Healy, O. , Bone, S., Campbell-Hay, K., Bargar, J., D. Snow, K.A. Weber. Nitrate-Stimulated uranium mobilization in groundwater. Nebraska Water Center Symposium. October 20, 2016. Lincoln, NE. (poster presentation)
14. Weber, K.A. Nolan, J.P. , Pan, D. , Healy, O. , Bone, S., Campbell-Hay, K., Bargar, J., and D. Snow. Nitrate-Stimulated Mobilization of Naturally Occurring Uranium in Groundwater. Geological Society of America Annual Meeting. September 25-28, 2016. Denver, CO. (poster presentation)
15. Nolan, J. P., C. Elofson, S. Bone, K. Campbell, D. Snow, J. Bargar, and K. A. Weber. Surface Complexation of Uranium(VI) in Suboxic Aquifers in the Presence of Uranium(IV) minerals. Geological Society of America Annual Meeting. September 25-28, 2016. Denver, CO.
16. Weber, K.A. Nolan, J.P. , Pan, D. , Healy, O. , Bone, S., Campbell-Hay, K., Bargar, J., and D. Snow. Nitrate-Stimulated Mobilization of Naturally Occurring Uranium in Groundwater. International Society for Microbial Ecology. August 21-26, 2016. Montreal, CA. (poster presentation)
17. Nolan, J.P., Pan, D., Healy, O., Bone, S., Campbell-Hay, K., Stange, M., Elofson, C., Wilson, T., Snow, D., Hanson, P., Joeckel, R.M., Bargar, J., and Weber, K.A. Sedimentary Natural Occurring Uranium in Alluvial Aquifers. 2016 Water for Food Global Conference, Lincoln, NE. April 2016. (poster presentation)
18. Pan, D., J. Nolan, K. H. Williams, M. J. Robbins, K. A. Weber. Abundance and Distribution of Microbial Cells and Viruses in an Alluvial Aquifer. (in review *Frontiers in Microbiology*)
19. Nolan, J. P. §; Bone, S.; Campbell, K.; Pan, D. ; Healy, O.; Elofson, C.; Joeckel, R. M.; Stange, M.; Wilson, T.; Hanson, P.; Bargar, J.; D., S.; Weber, K. A., Naturally Occurring Uranium in an Oxidic Alluvial Aquifer. (in preparation)
20. Nolan, J. P., R. Singh, C. Elofson, S. Bone, K. Campbell, D. Snow, J. Bargar, and K. A. Weber. Surface Complexation of Uranium(VI) in Suboxic Aquifers in the Presence of Uranium(IV)Minerals. (in preparation)

United States Geological Survey 104(g) Report (2016-2017)

Nitrate Mediated Mobilization of Naturally Occurring Uranium in Groundwater

Karrie A. Weber^{1,2} (PI), Daniel Snow³, and Kate M. Campbell⁴

¹School of Biological Sciences, University of Nebraska, Lincoln

²Department of Earth and Atmospheric Sciences, University of Nebraska, Lincoln

³Nebraska Water Center and School of Natural Resources, University of Nebraska, Lincoln

⁴United States Geological Survey, Boulder, CO

EXECUTIVE SUMMARY

This interdisciplinary project was conducted in collaboration between Drs. Karrie A. Weber and Daniel Snow, University of Nebraska-Lincoln (UNL) and Dr. Kate Campbell-Hay at the United States Geological Survey in Boulder, CO. Dr. Karrie A. Weber is an Assistant Professor in the School of Biological Sciences (joint appointment in Department of Earth and Atmospheric Sciences) with expertise in microbial metabolisms mediating soil/sedimentary carbon, nitrogen, and metal/radionuclide biogeochemical cycling. She is responsible for project oversight, experimental design, sample collection, laboratory experiments, and geochemical analyses. Dr. Snow is an Associate Research Professor in the School of Natural Resources and Director of the Water Sciences Laboratory in the Daugherty Water for Food Institute. Dr. Snow is a geochemist overseeing development of new methods for stable isotope analyses. Dr. Campbell-Hay is research chemist in the USGS NRP with an expertise in coupling UCODE to PHREEQC. She has conducted quantitative XRD analyses on oxic and anoxically preserved sediment samples as well as provided advice and support to students developing models based on data generated in the Weber laboratory. To identify the valence state of the uranium deposited in subsurface sediments X-Ray Adsorption Near Edge Spectroscopy (XANES) analysis was conducted in collaboration with Dr. John Bargar at Stanford Synchrotron Radiation Lightsource (SSRL) in 2015. The collaborative relationship with Dr. Bargar has continued in 2016-2017. Additional local collaborations were initiated at the beginning of the project and continue with city municipalities such as Hastings Utilities as well as Nebraska Natural Resource Districts to transfer to directly transfer knowledge gained from this research to regions experiencing nitrate and/or uranium water quality problems. In addition to the support of two female investigators, this project has supported the research of three graduate students at (2 Ph.D. students in the Department of Earth and Atmospheric Sciences (including one disabled veteran), 1 female Ph.D. student in the School of Biological Sciences and three undergraduate students, including one female supported through the Undergraduate Creative Activity and Research Experience Program (UCARE) at UNL. A postdoctoral scholar participating in the Water Advanced Research Innovation Fellowship program has also participated in this project.

Experimental research results have been disseminated by the PI and two graduate students to date at national and international scientific conferences/symposiums as well as locally in the state of the Nebraska to stakeholders and government agencies through workshops, meetings, and conferences (Department of Natural Resources, Natural Resource Districts local meeting). Drs. Weber and Campbell-Hay organized a topical session entitled “Biogeochemical Redox Cycling of Metals and Radionuclides” at the annual Geological Society of America meeting held in Boulder, CO in late September 2016. This session was sponsored by the GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division. One Ph.D. student completed a dissertation in August of 2016 which included one published manuscript (2015) and two additional manuscripts in preparation for submission related to the research conducted on this project. One

additional manuscript related to cell enumeration methods used in this study is currently under review in *Frontiers in Microbiology*. Research conducted on this project has resulted in the additional submissions of three additional research proposals submitted by Weber and a student research grant submitted to the Geological Society of America by Jeff Westrop (Ph.D. student in the Department of Earth and Atmospheric Sciences) conducting research building from results from this project.

BACKGROUND

Soluble uranium (U) is a regulated contaminant in public ground water supplies throughout the United States (Ayotte et al., 2011a), most notably in the High Plains and Central Valley Aquifers (Figure 1). Increasing occurrence of elevated U concentrations in drinking water in both urban and rural communities affects more than 6 million people increasing public supply treatment costs and human health concerns for private water supplies (Hakonson-Hayes et al., 2002). Health concerns and regulatory actions have prompted communities to seek alternative drinking water

sources or seek expensive treatment options that can exceed millions of dollars and thus has significant economic impacts. Mechanisms driving U mobilization in these aquifers remains poorly understood. In order to develop management strategies and prevent further contamination of drinking water sources, it is necessary to gain a fundamental understanding of the mechanisms stimulating U mobilization and improve predictive models. Two fundamental mechanisms have been recognized to drive U mobilization: *i*) desorption of U as a result of increased alkalinity or ground water removal and *ii*) dissolution of reduced U minerals. Though increasing bicarbonate alkalinity plays a significant role in mobilization (Ayotte et al., 2011b; Jurgens et al., 2010), in areas where U sources are in the form of reduced minerals and solids, elevated U concentrations cannot be explained without some mechanism for oxidation.

PROJECT OBJECTIVE

The **objective** of this project is to determine the mechanisms governing the oxidative dissolution of U(IV) leading to U mobility, and quantify the rate and extent of these reactions in order to develop a reactive transport model to predict U mobility in ground water.

SUMMARY OF HYPOTHESES AND APPROACH

1. *Microbial U reduction rates are slower than rates of oxidative dissolution of U (by O_2 , NO_3^- , and $Fe(III)$) thus resulting in U mobilization.*

Subsurface samples will be collected via GeoProbe[®] coring and geochemically characterized to identify zones of U(IV) bearing minerals as indicators of U reduction. Packed column experiments will be prepared from core sections containing U(IV) bearing minerals. Here we will experimentally determine the following:

- i. U(VI) reduction rates,
- ii. U(IV) oxidation rates in the presence of nitrate and oxygen,

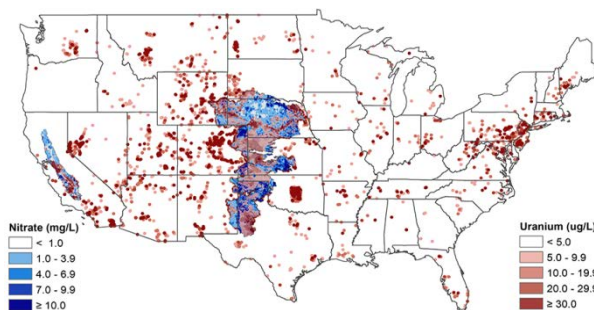


Fig. 1. Interpolated nitrate and U groundwater concentrations in the High Plains and Central Valley Aquifer from Nolan and Weber (2015).

- iii. U(IV) oxidation rates by abiotically and biogenically precipitated Fe(III) oxides,
- iv. Fe(III) reduction rates,
- v. Fe(II) oxidation rate by oxygen and nitrate.

2. *Oxidation of U coupled to nitrate reduction can be traced using ^{18}O -labeled NO_3^- .*

Subsurface samples testing positive for microbial U(IV) oxidation coupled to nitrate reduction will be placed in column experiments and amended with ^{18}O labeled NO_3^- . ^{18}O in the U(VI) species will be quantified.

EXPERIMENTAL RESULTS

Uranium is a ubiquitous, naturally occurring radionuclide commonly deposited in organic carbon-rich regions subsequent to weathering of igneous rock. The majority of U exists in soils and sediments as insoluble reduced U(IV) minerals and is generally insoluble and thus immobile in suboxic groundwater. It has been recognized that exposing reduced U(IV) minerals to oxidizing groundwater leads to oxidative dissolution producing a dissolved U(VI) species which is mobile in groundwater. However, beyond sites directly contaminated with U from anthropogenic activity (mining, milling, nuclear testing, and disposal of spent nuclear fuel), U contamination has not been considered a risk. Yet, nitrate, a common groundwater contaminant, indirectly or directly solubilizes U(IV). We had previously demonstrated a link between groundwater nitrate and U concentrations in two major US aquifers, High Plains and Central Valley (Figure 1) (Nolan and Weber, 2015). Areas with U exceeding the MCL (30 $\mu\text{g/L}$) have little to no direct anthropogenic U activity suggesting geogenic U contamination in these aquifers that may be driven by nitrate. These results were made publically available through *Environmental Science and Technology Letters*. This study also highlights that nitrate-mediated U mobilization is not restricted to isolated locations in Nebraska, but rather indicates that this may be a wide-spread issue.

The potential of microbially-catalyzed uranium mobilization directly from uranium-rich subsurface sediments collected from an alluvial aquifer in the Platte River Floodplain (USA) was conducted in upflow column reactors (Figure 2). Upflow meso-scale column reactors were packed with subsurface sediment and sterile sand (50% mass/mass) with bicarbonate buffered (pH 7.1) artificial groundwater as the influent (Figure 2). The source of subsurface sediment samples originated from a shallow alluvial aquifer in Nebraska from a region exhibiting fluctuating redox conditions which could give rise to U in groundwater. Uranium in other regions of this aquifer has been measured in the groundwater as high as 302 $\mu\text{g/L}$ (exceeding the MCL by 10 times). Nitrate concentrations in some regions are also above the MCL (10 mg/L) as high as 30 mg/L. The reduction potential within the borehole groundwater indicated a reduced environment and X-Ray Adsorption Near Edge Spectroscopy (XANES) of the fine fraction of subsurface sediments confirmed the presence of U(IV) (50% of total U) (Figure 3). The first incubation experiment reported in 2015-2016 demonstrated that the addition of nitrate stimulated the release of U(VI) into aqueous solution above the MCL relative to controls in which nitrate was omitted (Figure 4A). Nitrate was reduced to nitrite (Figure 4B) and is likely the result of the oxidation of natural organic carbon remaining in the sediments. Nitrite is recognized to rapidly



Figure 2. Upflow column reactors inside an anaerobic glove bag.

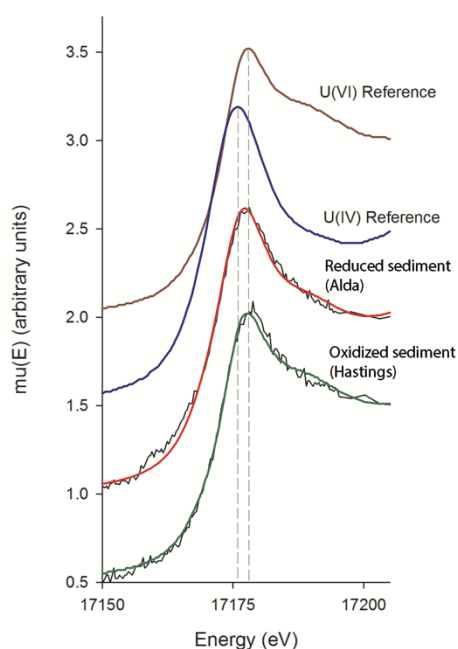


Figure 2. XANES spectra of subsurface sediments collected from a Reduced (Alda, NE) and Oxidized (Hastings, NE) aquifer. Sediment from the Oxidized system consisted of $85\% \pm 10\%$ U(VI), while Reduced aquifer sediment was consisted of $50\% \pm 10\%$ U(VI) and $50\% \pm 10\%$ U(IV).

such as phage predation that may lead to oscillations in total microbial cell abundance. We have employed the use and development of methods to enumerate both microorganisms and viruses in groundwater containing U (Pan et al. *in review*). The peaks and increase in the production nitrite appear to coincide with peaks or increase in U mobilization from the sediments further indicating a link between nitrate reduction to nitrite and U mobilization. A small amount of U(VI) was observed to release from sediments in which nitrate was omitted (Figure 4A). This result indicates that release of U from the sediments may also occur via desorption processes. As such the development of surface complexation

oxidize U(IV) to U(VI). Concurrent with the peak in nitrite are increases in total microbial cell numbers further supporting a biological role. The production of nitrite suggests that while nitrate-dependent U(IV) oxidizing microorganisms were identified in the sediment (3.0×10^6 cells g^{-1} sediment), nitrite production may be the mechanism driving the mobilization of U in these sediments. *Pseudomonas* spp. capable of nitrate reduction to nitrite have been successfully stimulated in this aquifer and compose a majority of the microbial community (Pan et al., 2014). Thus, reactive intermediates of nitrate reduction could serve as the direct or indirect oxidant of naturally occurring solid-phase U(IV) present in the sediments contributing to increases in groundwater U concentrations above the MCL. Interestingly there are spikes in total bacterial numbers. We have begun to explore mechanisms

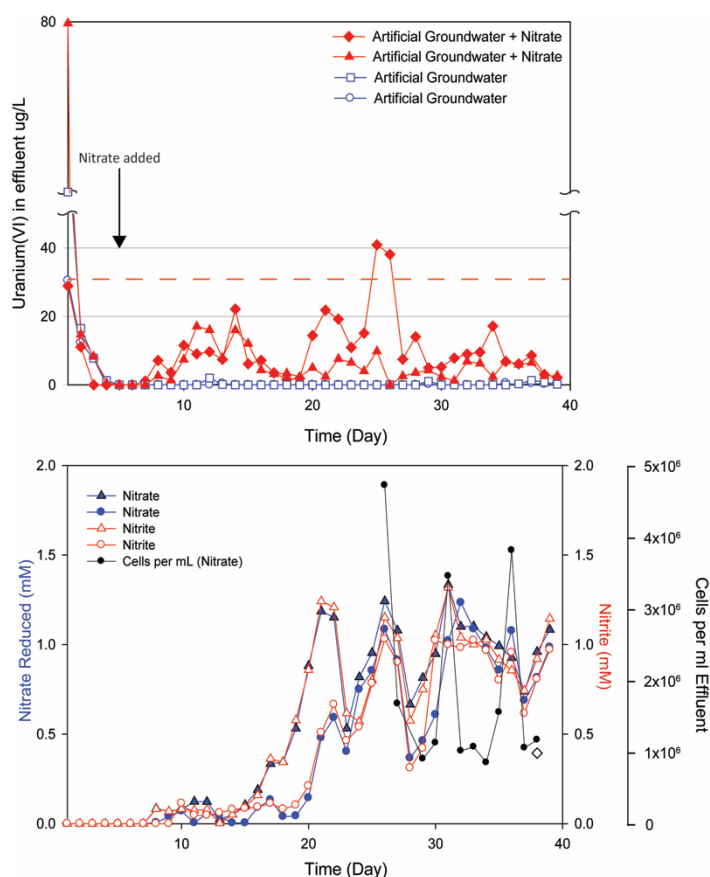


Figure 4. Upflow column reactors packed with 50% sand and 50% sediment. Nitrate was amended into two column reactors and omitted from two reactors (A). Nitrate was reduced to nitrite in reactors receiving nitrate input (B).

models to predict desorption from surfaces are necessary as well as oxidation rates.

The experimental design was repeated adding an additional control containing killed sediments (Gamma-irradiated total dose 20 kGy) in order to determine the role of biological nitrate reduction on U mobilization. Unfortunately, the dose of gamma-irradiation was not sufficient to kill the microorganisms responsible for nitrate reduction; nitrate was reduced to nitrite (data not shown). The experiment was continued to test alternative methods of biological inactivation. The addition of 50mM azide (an electron transport inhibitor) successfully inhibited nitrate reduction to nitrite and did not result in the mobilization of uranium (data not shown). While this treatment will not inactivate fermentative microorganisms, it will shut down nitrate reduction pathways which are coupled to electron transport. Thus effectively inhibiting the microbiological reduction of nitrate to nitrite, which we hypothesize is driving U mobilization. Over the final year of the project we will use sodium azide for the establishment of a killed control in order to demonstrate the role of microbiological catalysis on the mobilization of naturally occurring U in groundwater.

Interestingly following the pulse of uranium released into solution around day 25, U(VI) concentrations began to decrease. This could be a result of depletion of U(IV) in the sediments or the stimulation of the reduction of U(VI). We have observed the stimulation of reducing conditions with an influx of oxidant in a preliminary upflow meso-scale column experiment packed with subsurface sediments and amended with U(IV) as well as *in situ*. Using subsurface sediments collected from a different region of the aquifer also high in organic matter resulted in U retention and Fe loss (data not shown). This result can be explained by metal/radionuclide reduction. The loss of iron would occur as Fe(III) oxides are reductively dissolved to soluble Fe(II) and thus lost via advective transport in the effluent. Uranium would be retained as a result of continued reduction which would yield an insoluble U(IV) mineral that would not be transported. These results are counterintuitive as we would expect the addition of nitrate directly into reduced sediments to stimulate metal/radionuclide oxidation and thus promote U mobility and retain Fe as an Fe(III) oxide. We hypothesize that organic carbon serves as a redox buffer in these reduced sediments and can control U mobility. A proposal was submitted to the Department of Energy, Subsurface Biogeochemistry Research program in collaboration with John Bargar to further explore this hypothesis and investigate the link between carbon, nitrate, and uranium in natural and contaminated environments expanding our research to Riverton, WY.

Adsorption and Surface Complexation Modelling

The mobility of naturally occurring U in aquifers is influenced by redox and sediment adsorption as such adsorption reaction controlling mobility must be included in reactive transport models. Typically adsorption experiments are conducted under oxic conditions. However, U exists primarily in two oxidation states in the environment, the mostly soluble oxidized U(VI), and mostly insoluble reduced U(IV). The reduced state (U(IV)) can be rapidly oxidized by molecular oxygen (O₂) and thus create an experimental artifact. To date, previous studies have effectively quantified U(VI) sorption under oxic conditions and described the data using Surface Complexation Modeling (SCM). However, in an effort to test the effect of oxidizing conditions on experimental adsorption methods we used subsurface sediments collected from two different locations, one bearing the majority of solid-phase U in the oxidized state (U(VI)) and another bearing solid-phase U in the reduced state (U(IV)). X-ray absorption near edge spectroscopy (XANES) indicated that the “oxidized” subsurface sediment U contained $85\% \pm 10\%$ U(VI) and that the “reduced” sediment samples contained $50\% \pm 10\%$ U(IV) (Figure 3). A series of equilibrium adsorption experiments were conducted. In experiments amended with “reduced”

samples, up to $365.5 \mu\text{g kg}^{-1}$ of U from sediment was released during equilibrium experiments under oxic conditions ($\text{DO} > 7.0 \text{ mg L}^{-1}$) versus anoxic controls. Whereas, in experiments amended with oxidized sediment samples, no increase in U(VI) was observed. These results challenge standard techniques that rely on only using oxic fluids to test adsorption properties of solid sedimentary matrices. A surface complexation model for the data was generated using UCODE coupled to PHREEQC for equilibrium constant ($\text{Log } K^c$) optimization. These results revealed that suboxic sediment samples fit with data generated under anoxic conditions; whereas, data generated from an oxic aquifer fit with data generated under oxic conditions. These results indicate that sediment redox influences the experimental outcome of equilibrium adsorption experiments conducted under oxic conditions. Thus where reduced U(IV) exists in sediment, utilization of an anoxic method to account for adsorption to natural sediments should be used to avoid generation of experimental artefacts. Surface complexation models are currently being validated in collaboration with Dr. Kate Campbell at the USGS in Boulder, CO.

Together these data have demonstrated that nitrate will stimulate the oxidation of naturally occurring U(IV) in sediments. Over the remainder of the grant we will continue to focus on the development of a novel model integrating microbial reaction kinetics and surface complexation to predict rate of U mobilization. The surface complexation models already in development will contribute to the model Dr. Campbell is currently developing in collaboration with a graduate student in the Weber laboratory. Additional kinetic data will be obtained from a series of upflow meso-scale column reactors (Figure 2) as outlined below.

FUTURE PLANS:

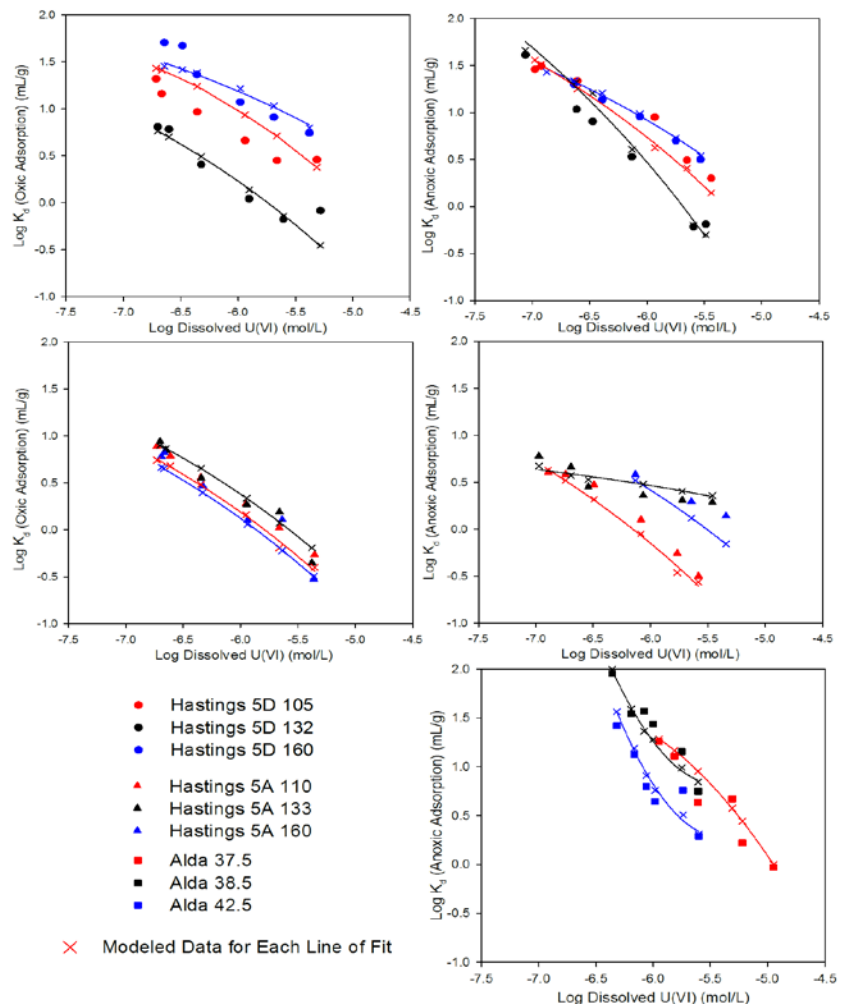


Figure 5. Equilibrium adsorption data with best fit reaction curves and modeled data results (denoted by x's) from “Oxidized” (Hastings) and “Reduced” (Alda).

Hypothesis 1: *Microbial U reduction rates are slower than rates of oxidative dissolution of U (by O_2 , NO_3^- , and Fe(III)) thus resulting in U mobilization.*

We have completed site and sediment characterization, adsorption experiments and development of surface complexation models are near completion, and we have completed the first column study demonstrating the mobilization of U(VI) in the presence of nitrate. We will continue to develop a surface complexation model and will determine the rates of U(VI) and Fe(III) reduction, U(IV) oxidation and U(VI) mobilization by O_2 and Fe(III) oxides to provide to Dr. Campbell for continued model development.

Hypothesis 2: *Oxidation of U coupled to nitrate reduction can be traced using ^{18}O -labeled NO_3^- .*

Development of method to trace oxidized U(VI) species using ^{18}O -labeled NO_3^- is underway but has faced some technological delays. Experiments involving the use of ^{18}O -labeled nitrate will be carried out after successful synthesis and analysis of uranium oxide (UO_2) of known oxygen isotope composition. One approach previously employed for uraninite synthesis uses a reduction of commercial uranyl chloride with hydrogen and could be adapted for this purpose using water with a known isotope composition (Weber et al., 2011). Because uranyl chloride already possess oxygen, and alternative approach to be investigated with involve reaction of depleted uranium metal with water (USDoE 2008). Moreover, we will try to take the ultraclave approach (Wang et al. 2008), where we plan to start with uranium tetrachloride as the starting material in ^{18}O -labelled water as solvent. Reaction products for each reaction will be analyzed using high temperature pyrolysis and conversion to carbon monoxide (Yin and Chen, 2014). Because EA-IRMS has not been employed for oxygen isotope analysis of uranium minerals, oxygen yield will be quantified and precision of the measurements evaluated through standard procedures. Traditionally, uraninite reduction by fluorination and conversion to carbon dioxide for isotope ratio mass spectrometry has been used (Fayek et al., 2011), though many of these off-line conversions have become unnecessary with the advent of high temperature on-line conversion chemistry. UO_2 with varying isotopic composition will be prepare and used as standards for analysis of uranium minerals generated during reduction of ^{18}O -labelled NO_3^- in column studies and possibly in batch experiments and even in natural samples. Methods for oxygen isotope analysis of nitrate (Silva et al., 2000) and phosphate (McLaughlin et al., 2006) have already been developed and are regularly used at the Water Sciences Laboratory. A final goal of the project is to develop a method for measuring the $\delta^{18}O$ of aqueous uranyl species which may be separated and concentrated using ion exchange and/or polymeric purification methods (Aly and Hamza, 2013).

Finally, development of a method for speciation of dissolved forms of reduced U(IV) and oxidized U(VI) uranium for the project will be facilitated by recent acquisition of a new Thermo ICAP RQ inductively coupled plasma mass spectrometer (ICP-MS) coupled to a ICS5+ gradient ion chromatography system. The ICAP RQ is replacing an obsolete, and nearly inoperative, ICP-MS at the Water Sciences Laboratory that has also slowed progress on this project.

PUBLICATIONS (2016-2017)

‡Undergraduate/Post-baccalaureate Student Contributing Author

§Graduate Student Contributing Author

Published

Nolan, J. P. § 2016. Mobilization of Naturally Occurring Uranium in Sediment into Groundwater (Dissertation).

In preparation

Pan, D.§, J. Nolan§, K. H. Williams, M. J. Robbins, **K. A. Weber**. Abundance and Distribution of Microbial Cells and Viruses in an Alluvial Aquifer. (*in review Frontiers in Microbiology*)

Weber, K. A.; Healy, O. §; Nolan, J. §; Pan, D.; Campbell, K.; Heithoff, A.; Spanbauer, T. ‡; Snow, D., Nitrate stimulated uranium mobilization in groundwater. *in prep*.

Nolan, J. P. §, R. Singh, C. Elofson‡, S. Bone, K. Campbell, D. Snow, J. Bargar, and K. A. Weber. Surface Complexation of Uranium(VI) in Suboxic Aquifers in the Presence of Uranium(IV)Minerals. *in prep*.

Nolan, J. P. §; Bone, S.; Campbell, K.; Pan, D. §; Healy, O. §; Elofson, C. ‡; Joeckel, R. M.; Stange, M.; Wilson, T.; Hanson, P.; Bargar, J.; D., S.; Weber, K. A., Naturally Occurring Uranium in an Oxic Alluvial Aquifer. *in prep*.

WORKSHOP, SEMINAR AND CONFERENCE PROCEEDINGS

*Presenting Author

‡Undergraduate/Post-baccalaureate Student Contributing Author

§Graduate Student Contributing Author

Weber, K. A. Mobilization of Uranium in Groundwater: What is the role of nitrate? Nebraska Water Center. April 13, 2016

Weber, K.A. Uranium and Nitrate in Groundwater. Nebraska Natural Resource District Conference, Kearney, NE, March 1, 2016.

Weber, K. A. Keynote. Life Beneath Our Feet: Influence on Water Quality. Iowa State University. Environmental Science Graduate Research Symposium. April 1, 2016.

Weber, K.A. Nitrate and Uranium in Groundwater, NRD Annual Conference, Kearney, NE, March 1, 2016.

Westrop, J.* §, Nolan, J.P. § , Pan, D. § , Healy, O. § , Bone, S., Campbell-Hay, K., Bargar, J., D. Snow, **K.A. Weber**. Nitrate-Stimulated uranium mobilization in groundwater. Nebraska Water Center Symposium. October 20, 2016. Lincoln, NE. (*First Place Poster Award*)

Weber, K.A*. Nolan, J.P. §, Pan, D. §, Healy, O. §, Bone, S., Campbell-Hay, K., Bargar, J., and D. Snow. Nitrate-Stimulated Mobilization of Naturally Occurring Uranium in Groundwater. Geological Society of America Annual Meeting. September 25-28, 2016. Denver, CO.

Nolan, J. P., C. Elofson, S. Bone, K. Campbell, D. Snow, J. Bargar, and **K. A. Weber**. Surface Complexation of Uranium(VI) in Suboxic Aquifers in the Presence of Uranium(IV) minerals. Geological Society of America Annual Meeting. September 25-28, 2016. Denver, CO.

Weber, K.A.*. Nolan, J.P. §, Pan, D. §, Healy, O. §, Bone, S., Campbell-Hay, K., Bargar, J., and D. Snow. Nitrate-Stimulated Mobilization of Naturally Occurring Uranium in Groundwater. International Society for Microbial Ecology. August 21-26, 2016. Montreal, CA.

Nolan, J.P., Pan, D., Healy, O., Bone, S., Campbell-Hay, K., Stange, M., Elofson, C., Wilson, T., Snow, D., Hanson, P., Joeckel, R.M., Bargar, J., and **Weber, K.A.** *Sedimentary Natural Occurring Uranium in Alluvial Aquifers*. 2016 Water for Food Global Conference, Lincoln, NE. April 2016.

REFERENCES CITED

- Aly, M. M., and Hamza, M. F., 2013, A Review: Studies on Uranium Removal Using Different Techniques. Overview: Journal of Dispersion Science and Technology, v. 34, no. 2, p. 182-213.
- Ayotte, J. D., Gronberg, J. M., and Apodaca, L. E., 2011a, Trace Elements and Radon in Groundwater Across the United States: U.S. Geological Survey Scientific Investigations Report
- Ayotte, J. D., Szabo, Z., Focazio, M. J., and Eberts, S. M., 2011b, Effects of human-induced alteration of groundwater flow on concentrations of naturally-occurring trace elements at water-supply wells: Applied Geochemistry, v. 26, no. 5, p. 747-762.
- Fayek, M., Horita, J., and Ripley, E. M., 2011, The oxygen isotopic composition of uranium minerals: A review: Ore Geology Reviews, v. 41, no. 1, p. 1-21.
- Hakonson-Hayes, A. C., Fresquez, P. R., and Whicker, F. W., 2002, Assessing potential risks from exposure to natural uranium in well water: J Environ Radio v. 59, no. 1, p. 29-40.
- Jurgens, B. C., Fram, M. S., Belitz, K., Burow, K. R., and Landon, M. K., 2010, Effects of Groundwater Development on Uranium: Central Valley, California, USA: Ground Water, v. 48, no. 6, p. 913-928.
- McLaughlin, K., Paytan, A., Kendall, C., and Silva, S., 2006, Oxygen isotopes of phosphatic compounds--Application for marine particulate matter, sediments and soils: Marine Chemistry, v. 98, no. 2-4, p. 148-155.
- Nolan, J., and Weber, K. A., 2015, Natural Uranium Contamination in Major U.S. Aquifers Linked to Nitrate: Environmental Science & Technology Letters, v. 2, no. 8, p. 215-220.
- Pan, D., Nolan, J., Williams, K. H., Robbins, M. J., and Weber, K. A., *in review*, Abundance and Distribution of Microbial Cells and Viruses in an Alluvial Aquifer.
- Pan, D., Watson, R., Wang, D., Tan, Z. H., Snow, D. D., and Weber, K. A., 2014, Correlation between viral production and carbon mineralization under nitrate-reducing conditions in aquifer sediment: ISME J, v. 8, no. 8, p. 1691-1703.

- Silva, S. R., Kendall, C., Wilkison, D. H., Ziegler, A. C., Chang, C. C. Y., and Avanzino, R. J., 2000, A new method for collection of nitrate from fresh water and the analysis of nitrogen and oxygen isotope ratios: *Journal of Hydrology*, v. 228, no. 1-2, p. 22-36.
- Wang, Q., Li, G.-D., Xu, S., Li, J.-X., Chen, J.-S., 2008, Synthesis of uranium oxide nanoparticles and their catalytic performance for benzyl alcohol conversion to benzaldehyde. *J Materials Chem*, v. 18, p. 1146-1152.
- Weber, K. A., Thrash, J. C., Van Trump, J. I., Achenbach, L. A., and Coates, J. D., 2011, Environmental and Taxonomic Bacterial Diversity of Anaerobic Uranium(IV) Bio-Oxidation *Appl Envir Microbiol*, v. 77, p. 4693 - 4696.
- Yin, X., and Chen, Z., 2014, Measuring oxygen yields of a thermal conversion/elemental analyzer-isotope ratio mass spectrometer for organic and inorganic materials through injection of CO: *J Mass Spectrom*, v. 49, no. 12, p. 1298-1305.

Evaluation of changing irrigation management on ground water recharge and quality

Basic Information

Title:	Evaluation of changing irrigation management on ground water recharge and quality
Project Number:	2016NE286B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	NE-01
Research Category:	Ground-water Flow and Transport
Focus Categories:	Groundwater, Water Quality, Water Quantity
Descriptors:	None
Principal Investigators:	Troy Edward Gilmore, Daniel Davidson Snow

Publications

There are no publications.

2017 Project Report

Evaluation of changing irrigation management on ground water recharge and quality

Troy Gilmore^{1,2} and Daniel Snow³

¹Conservation and Survey Division - School of Natural Resources, Univ. of Nebraska, Lincoln

²Department of Biological Systems Engineering, University of Nebraska, Lincoln, NE

³Water Sciences Laboratory, Nebraska Water Center, University of Nebraska, Lincoln, NE

1. Problem and Research Objectives

Irrigation practices may have a strong influence on groundwater levels and the amount of nitrate (NO₃) leached to groundwater. This study focuses on the potential influence of water resources management, especially irrigation practice, in the North Platte Natural Resources District (NPNRD) in western Nebraska. Historically, the Dutch Flats area within NPNRD has relied on surface irrigation techniques, using surface water delivered by canals and laterals. Surface irrigation typically has lower efficiency compared to center-pivot (sprinkler) irrigation, which leads to greater deep drainage (i.e., recharge), but also has the potential for increased leaching of NO₃ to groundwater. In addition to recharge from surface irrigation, the Dutch Flats area receives significant recharge through leakage from the canals and laterals.

In the late 1990s, the U.S. Geological Survey (USGS) conducted an intensive study of groundwater age, recharge rates, and NO₃ concentrations ([NO₃]) in the Dutch Flats area (Verstraeten et al., 2001a, 2001b, Böhlke et al., 2007). The average groundwater age (time between recharge and sampling, estimated from environmental tracers in groundwater) in the aquifer was only 8.8 years suggesting that the aquifer would respond relatively quickly to changes in water resources and/or nutrient management. The relatively low groundwater ages also indicated that the groundwater system was reliant on significant sources of recharge other than local precipitation.

Böhlke et al. (2007) hypothesized that groundwater residence times and [NO₃⁻] in the Dutch Flats area may be impacted if recharge from canals and/or irrigation were significantly reduced. Since the late 1990s, there has been a significant shift in irrigation practices, with many center-pivot systems installed between 2000 to present. These changes have occurred over a time period with length similar to the time-scale of groundwater age in the Dutch Flats area (i.e., the expected aquifer response time), leading to an opportunity to test the hypothesis that water resources management, and irrigation practice specifically, could significantly influence groundwater levels and groundwater [NO₃] in the aquifer.

The purpose of this study is to evaluate trends in groundwater levels and [NO₃] in the North Platte Natural Resources District, and to determine whether groundwater age-dating techniques can show a significant change in groundwater travel times (and therefore, recharge rate) as a result of changing water resources management in the Dutch Flats area. The results of this project will be used to inform stakeholders and water resources managers of current conditions in

the aquifer, and provide a case study of how management decisions may have impacted the groundwater system

2. Methodology

Groundwater samples to be analyzed for age-dating tracers ($^3\text{H}/^3\text{He}$) were collected from wells and stored in refrigeration-grade copper tubes sealed with refrigeration pinch clamps (^3He and noble gases required for interpretation, including ^4He , Ne, Ar, Kr, and Xe) and in 500 mL HDPE bottles (^3H). Groundwater samples were collected for analysis of $[\text{NO}_3]$ in addition to $^{15}\text{N}\text{-NO}_3$ and $^{18}\text{O}\text{-NO}_3$. Age-dating tracers analysis were scheduled to be analyzed at the University of Nebraska Water Sciences Laboratory, but after analytical equipment delays were ultimately sent to the Dissolved and Noble Gas Laboratory at the University of Utah.

Prior to sampling, wells were purged using a variable-speed stainless steel submersible pump. At least one well casing volume was purged with the submersible pump located near the top of the water column. The pump was then lowered to the top of the well screen. Purging continued until groundwater parameters stabilized (pH, specific conductivity, dissolved oxygen; measured using Hydrolab MS5 sonde and flow cell). Total dissolved gas pressure was also monitored during purging.

Sampling was focused on well nests (i.e., 2-3 wells installed at the same location, with screens located at different depths) that were installed and sampled during the previous USGS study, so direct comparisons could be made to previous observations of groundwater chemistry and age. One well nest (1G) adjacent to the main canal was sampled in March 2016, prior to the canal being filled. The same well nest was sampled again in October 2016, after the irrigation season was over. Nine additional wells (at well nests 1E, 2D, 1C, and 1L) were sampled in August 2016.

In addition to groundwater sampling, we also obtained existing data sets for the NPNRD, including precipitation records, groundwater levels, and historical $[\text{NO}_3]$. The data sources were NOAA (<https://www.ncdc.noaa.gov/IPS/lcd/lcd.html>), the Conservation and Survey Division (Aaron Young, personal comm., Nov 2016), and the Nebraska Quality-Assessed Agrichemical Contaminant Database (<http://nednr.nebraska.gov/Clearinghouse/Clearinghouse.aspx>), respectively.

3. Project Results

Preliminary trend analyses for entire NPNRD

We analyzed available groundwater elevation data for the entire NPNRD (Fig. 1) to evaluate broad trends across the NRD. Since 1985 (roughly 15 years prior to the USGS study) groundwater levels have generally declined (Fig. 2), based on the average annual depth to water. Groundwater elevations could be lower in part due to lower precipitation in more recent years (although differences in precipitation in 1985-1999 versus 2000-2015 are within inter-annual variability (Table 1)), but could also be related to water resources management and irrigation practices in the NPNRD.

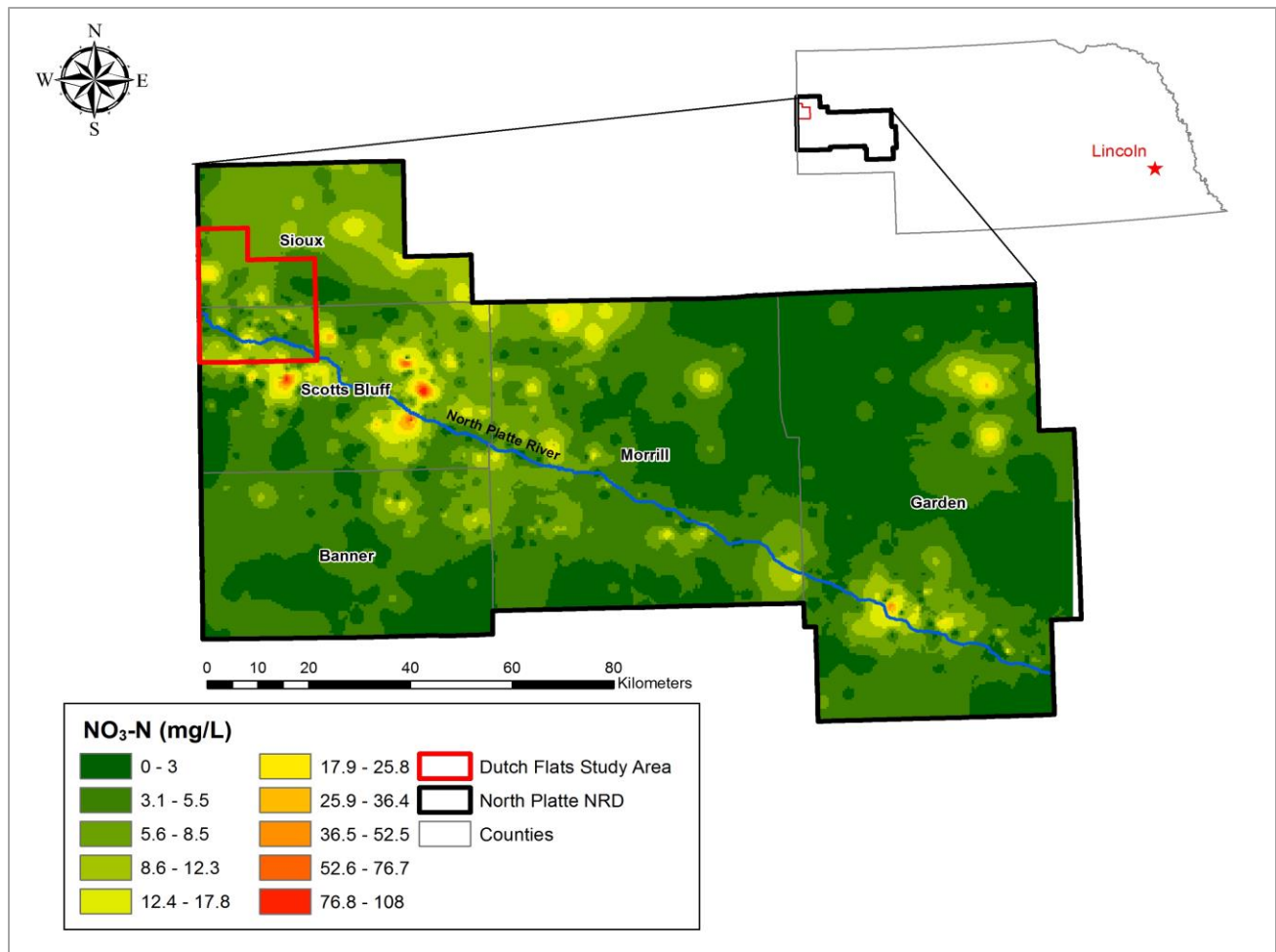


Figure 1. North Platte Natural Resources District (NPNRD) and Dutch Flats boundaries, with interpolated map of average [NO₃] in groundwater samples collected from wells with screened intervals of ≤ 15.2 m during the time period of 1974 - 2014.

Table 1. Precipitation and snowfall data before and after the most recent study of groundwater recharge and quality.

	Precipitation	Snowfall
	(inches)	(inches)
1985-1999	17.3 (3.9)	44.3 (15.7)
2000-2014	13.9 (4.3)	40.2 (17.4)
POR	15.3	39.0

Standard deviation for time period shown in parentheses

POR = period of record (121 yrs for precipitation, 89 yrs for snowfall)

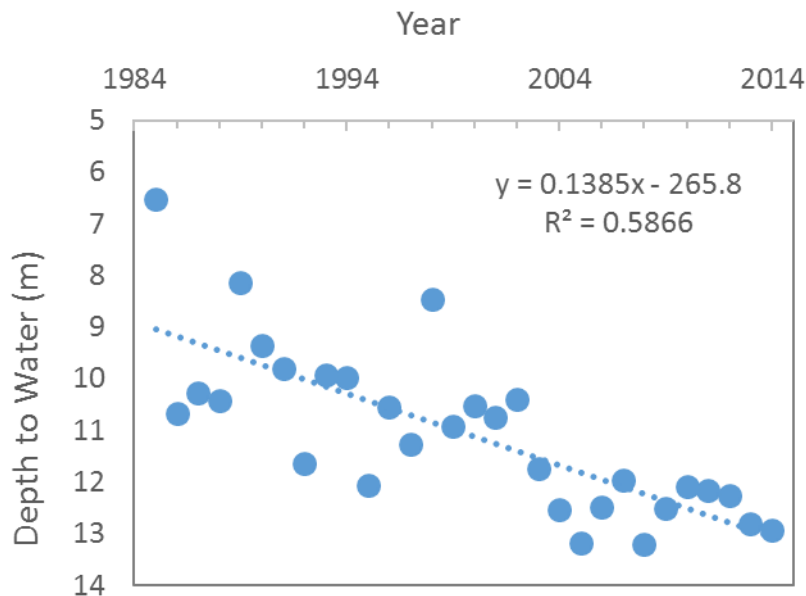


Figure 2. Average annual depth to water in NPNRD, suggesting lower groundwater elevations over time.

Groundwater $[\text{NO}_3]$ have lower maximum values in more recent years (Fig. 3), suggesting less leaching of NO_3 to groundwater across the NRD. Historical $[\text{NO}_3]$ data were not normally distributed (even after data transformations), so although mean $[\text{NO}_3]$ appeared generally lower during the time period of 2000-2015 versus 1985-1999, we could not test for statistical significance. Instead, we used a Mann-Whitney non-parametric U test and found that the median $[\text{NO}_3]$ was significantly different for the two time periods (Table 2).

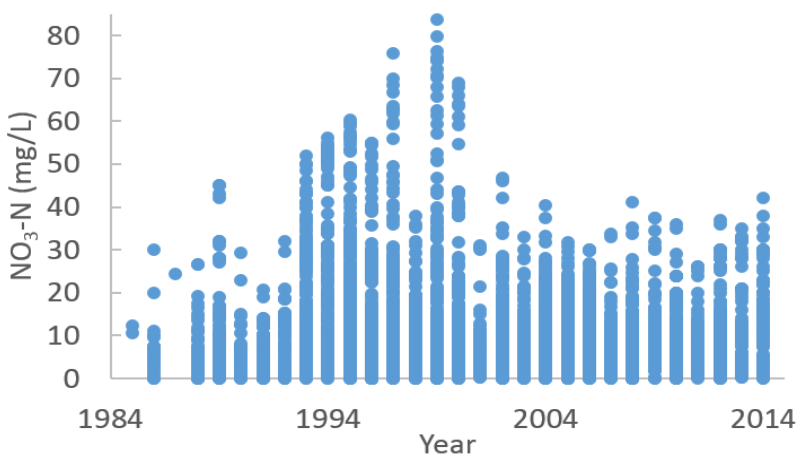


Figure 3. Groundwater $[\text{NO}_3]$ in the NPNRD, showing generally lower maximum $[\text{NO}_3]$ since the turn of the century. Four likely outliers from 1986 data have been removed from this figure.

Table 2. Mean (with standard deviation in parentheses) and median [NO₃] for two different time periods, 1985-1999 and 2000-2014, for well different well depths in the NPNRD.

Well Depth (m)	Period of Record	Well Count	Mean Well Depth (m)	Mean NO ₃ -N (mg/L)	Median NO ₃ -N (mg/L)
0-15.2	1985-1999	1308	10.0	14.3 (15.4)	8.4
	≥ 2000	2247	10.7	8.0 (8.3)	*5
0-30.5	1985-1999	2929	17.4	9.8 (12.3)	6.0
	≥ 2000	4531	17.2	6.9 (6.7)	*4.8
All (0-265.2)	1985-1999	3973	25.7	8.5 (11.1)	5.2
	≥ 2000	6372	25.7	6.2 (6.1)	*4.3

*2000-2014 median [NO₃] is significantly different compared to 1985-1999 median [NO₃] ($p < 0.01$, $\alpha = 0.05$, Mann-Whitney Nonparametric U test).

Preliminary comparisons of USGS and current study in Dutch Flats area

Specific conductance (spC, $\mu\text{S}/\text{cm}$) from 2016 sampling and the previous USGS study (Böhlke et al., 2007) was similar for most samples, with slope close to 1 (Fig. 4). The two 2016 samples with highest spC correspond to high-[NO₃] samples in 2016. The highest [NO₃] observed in 2016 was from the shallow well (1G-S) near the main canal, collected prior to irrigation season. The sample was collected after an intense precipitation event, down-gradient of a feedlot, and exhibited a higher $\delta^{15}\text{N}\text{-NO}_3$ signature (17‰) than any other samples (mean of 0.3‰ for the other 11 available values; Fig. 5). The other high-[NO₃] sample (1E-S, 45 mg N/L) was collected from a shallow well that has historically had [NO₃] of about 12 mg N/L, although the most recent (2010) sample was 18 mg N/L.

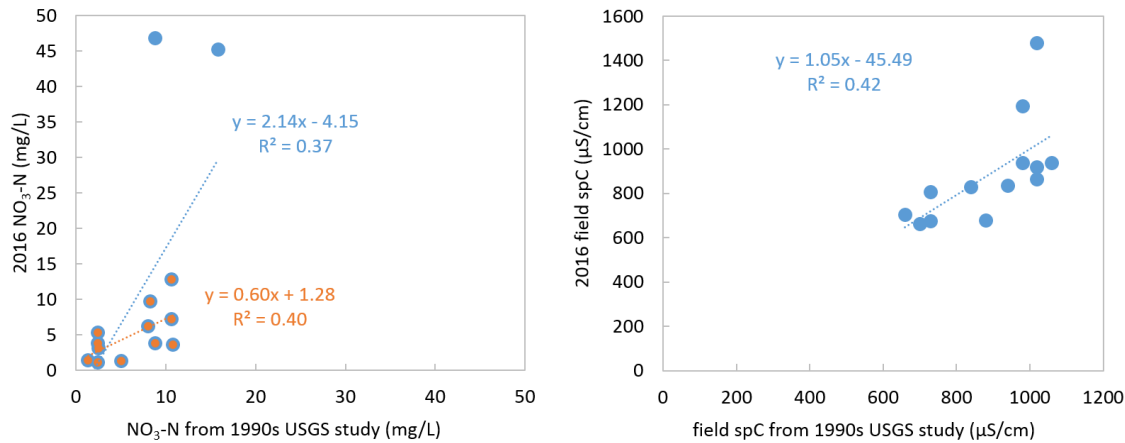


Figure 4. [NO₃] and specific conductance (spC) for samples collected in 2016 compared to samples collected from the same wells in the 1990s USGS study (Böhlke et al., 2007). In the [NO₃] plot, regression lines are shown for data including two high-[NO₃] samples in 2016 (blue line and regression equation), or excluding those two points (orange). Those two high-[NO₃] samples were from shallow wells at their respective well nests, and were also the two wells with highest spC in 2016.

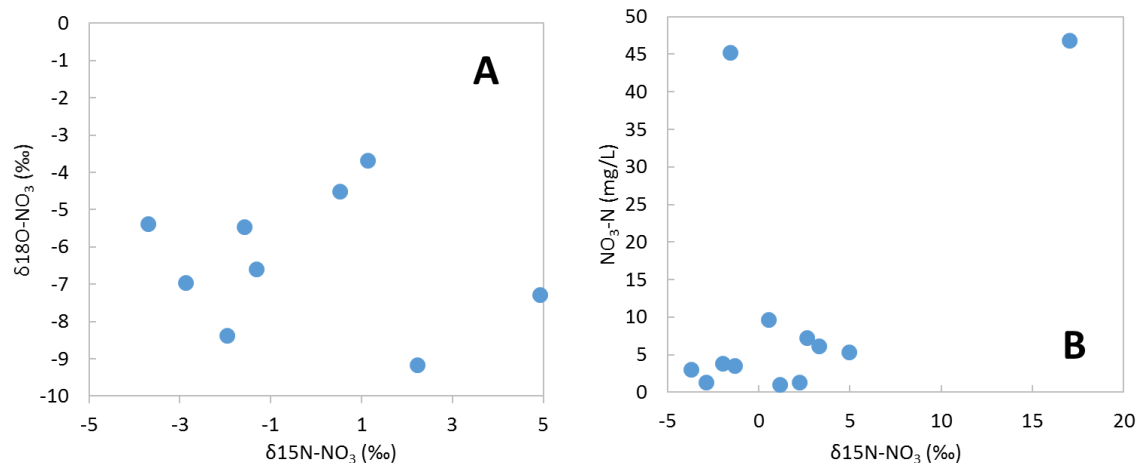


Figure 5. Isotope data suggesting (A) $\delta^{15}\text{N-NO}_3$ and $\delta^{18}\text{O-NO}_3$ in the range of NH_4 fertilizer, precipitation, and soil N for samples collected in August 2016 ($n = 9$), and (B) including the two different $\delta^{15}\text{N-NO}_3$ signatures for the two high- $[\text{NO}_3]$ groundwater samples. The sample with higher $\delta^{15}\text{N-NO}_3$, which can be indicative of animal waste, was collected from a shallow well down-gradient of a feedlot. The remaining ($n=11$) samples have $\delta^{15}\text{N-NO}_3$ more consistent with commercial fertilizer.

Samples collected for groundwater age-dating tracer analysis are currently being processed at the University of Utah. Once the tracer concentrations and accompanying noble gas data are available, groundwater ages will be estimated and compared to previous groundwater age estimates from the prior USGS study in the Dutch Flats area.

4. Significance

Although some lab analyses are still pending, the funding from this project has led to additional collaboration with the USGS Nebraska Water Science Center. As part of Martin Wells' (the student directly supported by this grant) thesis project, we will be refining and using a groundwater model developed by USGS for NPNRD to further expand on the spatial and temporal trend analyses already underway. The USGS model has already been shared with Martin (Amanda Flynn, personal communication, May 2017), and USGS is involved in developing plans for integrating new (2016) and existing data to further explore how water resources management may impact temporal and spatial trends, as observed thus far from field data. Isotope data (Fig. 5) suggested NO_3 in most samples was consistent with commercial fertilizer, although soil N and manure could not be ruled out (Kendall 1998; their Fig. 16.9).

This project has also contributed to PI Gilmore's Extension program through initiation of relationships with water resources stakeholders in Nebraska. Outreach has included field training for NRD staff on sampling techniques for groundwater age-dating tracers. The 104b grant has also strengthened the development of PI Gilmore's research program. He recently submitted a collaborative NSF proposal focused on bridging gaps between groundwater age-dating and transit time modeling techniques. Lastly, PI Gilmore used additional funds to collect duplicate groundwater samples for age-dating analysis, which will allow for an inter-lab comparison

between the University of Nebraska (when operational) and the well-established University of Utah Dissolved and Noble Gas laboratory operated by Kip Solomon.

Graduate student Martin Wells presented a research poster as part of the 2017 Daugherty Water for Food Global Conference (April 10-12, 2017) student poster competition. Martin will present project results at the 2017 Association of Agricultural and Biological Engineers Annual International Meeting in Spokane, WA (July 16-19, 2017), and is currently working on a Nebraska Extension publication focused on previous and current groundwater age-dating studies in Nebraska, as well as potential future uses for the technique in Nebraska.

References Cited:

- Böhlke, J. K., I. M. Verstraeten, and T. F. Kraemer (2007), Effects of surface-water irrigation on sources, fluxes, and residence times of water, nitrate, and uranium in an alluvial aquifer, *Applied Geochemistry*, 22(1), 152–174, doi:10.1016/j.apgeochem.2006.08.019.
- Kendall, C. (1998) Tracing Nitrogen Sources and Cycling in Catchments, in [*Isotope Tracers in Catchment Hydrology*](#), C. Kendall and J. J. McDonnell (Eds.). Elsevier Science B.V., Amsterdam. pp. 519-576 [accessed online 5/26/2017].
- Verstraeten, I.M., G.V. Steele, J.C. Cannia, D.E. Hitch, K.G. Spreter, J.K. Böhlke, T.F. Kraemer, and J.S. Stanton (2001b), Interaction of surface water and ground water in the Dutch Flats area, western Nebraska, 1995–1999, *U.S. Geological Survey Water Resources Investigations Report 2001-4070*, 56 p.
- Verstraeten, I.M., G.V. Steele, J.K. Böhlke, T.F. Kraemer, K.E. Wilson, and A.E. Carnes (2001a), Selected field and analytical methods and analytical results in the Dutch Flats area, western Nebraska, 1995-99, *U.S. Geological Survey Open File Report, 00-413*, 53 p.

Performance Assessment of Irrigation Systems in a Changing Climate of West Central Nebraska

Basic Information

Title:	Performance Assessment of Irrigation Systems in a Changing Climate of West Central Nebraska
Project Number:	2016NE287B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	NE-003
Research Category:	Water Quality
Focus Categories:	Irrigation, Water Quantity, Water Quality
Descriptors:	None
Principal Investigators:	Daran Ray Rudnick, Chuck A Burr, Tim Shaver, Derrel L Martin, Greg Kruger, Francisco MunozArriola, Matt Stockton

Publication

1. Singh, J., T. Lo, D.R. Rudnick, T.J. Dorr, C.A. Burr, R. Werle, T.M. Shaver, F. Munoz-Arriola, 2017, Performance analysis of electromagnetic soil water sensors in a loam soil, "In Preparation"

Performance Assessment of Irrigation Systems in a Changing Climate of West Central Nebraska

**Daran R. Rudnick¹, Tim Shaver², Derrel Martin¹,
Greg Kruger², Francisco Arriola-Muñoz¹, Matt Stockton³, and Chuck Burr⁴**

¹Department of Biological Systems Engineering, University of Nebraska-Lincoln

²Department of Agronomy and Horticulture, University of Nebraska-Lincoln

³Department of Agricultural Economics, University of Nebraska-Lincoln

⁴Nebraska Extension

Statement of Problem:

In the semi-arid climate of western NE, irrigation is vital for the economic viability of individual producers as well as for the region. Irrigation provides local producers with supplemental water when stored soil water is exhausted and precipitation is deficient to meet crop water demand. In general, the realized deficit between irrigated and rainfed agriculture decreases along the precipitation gradient from western to eastern NE with long-term (1996-2012) average seasonal precipitation ranging from 201 mm (Scotts Bluff County) to 466 mm (Richardson County) (Rudnick et al., 2015). For example, the long-term deficit between irrigated and rainfed maize production in Richardson County (southeast NE), Clay County (south central NE), Lincoln County (west central NE), and Scotts Bluff County (western NE) is 2.95, 4.96, 6.72, and 6.28 Mg ha⁻¹, respectively (www.nass.usda.gov). Unfortunately, west and west central NE have to contend with greater precipitation deficits and rely more heavily on irrigation for crop production as compared to central and eastern NE. With an increase in dependency on irrigation in western NE coupled with water demands from other sectors or uses (e.g., stream flow), concerns have developed around ground and surface water availability as well as environmental degradation issues associated with excessive use of water and nitrogen (N) fertilizers. Furthermore, these concerns have raised questions about the sustainability of irrigation in the region, especially with increases in the frequency and severity of drought conditions projected due to climate change.

Several actions are in place to help mitigate the effects of irrigation on the quantity and quality of ground and surface water resources in NE. For example, the NE Natural Resource Districts (NRDs) are able to sanction water management regulations, including allocating groundwater, augmenting surface water, requiring flow meters, instituting well drilling moratoriums, requiring water use reports, and restricting the expansion of irrigated acres as well as establishing groundwater management areas to protect water quality, such as high groundwater nitrate (NO₃-N) levels (Ferguson, 2015). A well-recognized opportunity that has not been fully realized is the conversion of less efficient irrigation systems to more efficient systems to decrease irrigation water withdrawal, energy consumption, and potential nitrate leaching. Various types of irrigation systems exist to apply water to a producer's field, such as sprinkler irrigation via center pivot or lateral move, furrow irrigation (a.k.a. gravity or surface irrigation), subsurface drip irrigation (SDI), and more recently mobile drip irrigation (MDI). The irrigation systems vary in the range of water application efficiency, which is a measure of how well an irrigation system delivers water from a conveyance system to the crop. The potential water application efficiency of a well-designed and managed system is 75 to 85% for center pivot or lateral move, 45 to 65% for conventional furrow irrigation, and greater than 95% for SDI (Irmak et al., 2011). The water application efficiency values are also dependent on soil and climatic conditions, in addition to crop,

water, nutrient, and land management practices. In a review, Lamm (2015) reported that maize grain yield under SDI on average increased 4% as compared with alternative irrigation systems (furrow irrigation, surface drip, and sprinkler). Furthermore, in most studies water productivity was generally greater for SDI than alternative systems, due to less soil water evaporation, less deep percolation, and reduced irrigation and precipitation runoff (Lamm, 2015). However, under certain conditions the SDI systems resulted in lower grain yield as compared to the alternative systems; therefore, it is important that differences in system performance in terms of grain yield, irrigation water use efficiency, irrigation capacity requirements, economics, and environmental impact are assessed for areas of interest.

Research Objectives:

The overall goal of the project was to collect initial data to establish the potential economic, environmental, and crop response impacts across various irrigation system types in a changing climate in west central NE. The specific objective was to conduct a side by side comparison between similarly managed sprinkler and SDI systems at the UNL West Central Research and Extension Center in North Platte, NE and between sprinkler and MDI systems at the UNL Brule Water Laboratory near Big Springs, NE. This research will provide valuable information for crop, hydrologic, and economic models that look to understand crop response to irrigation management under different irrigation system types. Also, this research provided pre-professionals with hands on training of various irrigation system types.

Material and Methods:

Site Descriptions:

This grant supported research at two sites: North Platte and Big Springs. The North Platte site is part of the University of Nebraska-Lincoln West Central Research and Extension Center (WCREC) and is situated on alluvial terraces of the South Platte River. The terrain is nearly level, and the soils are medium in texture—typically of the Cozad soil series (Coarse-silty, mixed, superactive, mesic Typic Haplustolls; NRCS, 2005). The elevation is 860 m above mean sea level (NSCO, 2017) and the average annual precipitation is 524 mm (PRISM Climate Group, 2014). The Big Springs site is part of the University of Nebraska-Lincoln Brule Water Resources Field Laboratory (BWL) and is situated on a plateau between the North Platte and South Platte Rivers. The terrain is nearly level, and the soils are medium-fine in texture—typically of the Kuma soil series (Fine-silty, mixed, superactive, mesic Pachic Argiustolls; NRCS, 2006). The elevation is 1,128 m above mean sea level (NSCO, 2017) and the average annual precipitation is 459 mm (PRISM Climate Group, 2014).

Intact soil cores were obtained from both sites using a direct-push hydraulic soil probe. These cores were cut into subsamples of 0.15 m length at the North Platte site and of 0.30 m length at the Big Springs site. Bulk density was calculated by dividing the oven-dried weight of a soil subsample by the undisturbed volume of that subsample. Organic matter content and textural composition were determined by the loss-on-ignition and the hydrometer methods, respectively, at commercial agricultural testing laboratories. Ward Laboratories in Kearney, NE was used for the BWL site and American Agricultural Laboratory in McCook, NE was used for the WCREC site. At WCREC, bulk density was higher at the 0.15 and 0.30 m depths than at the deeper sampled depths (Figure 1a). Organic matter content decreased with soil depth (Figure 1b). Soil texture was progressively coarser from 0.15 to 0.76 m and clay content was similar from 0.76 to 1.37 m (Figures 1c-d). At the BWL site, bulk density and organic matter content decreased with increasing depth (Figures 1a-b). Sand content was similar

among the sampled depths (Figure 1c), whereas clay content was higher at the 0.15, 0.46, and 0.76 m depths than at the 1.07 and 1.37 m depths (Figure 1d).

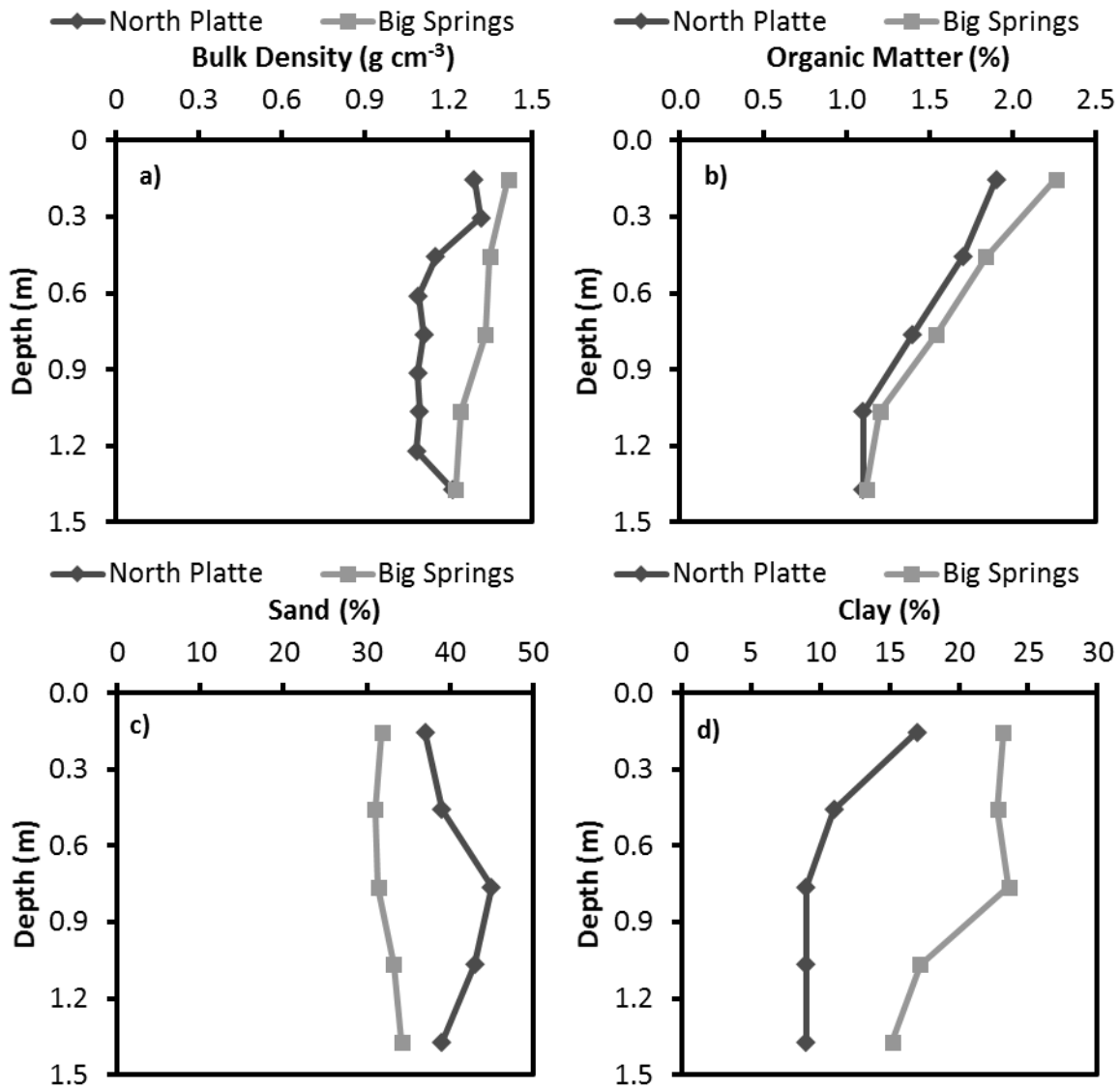


Figure 1. a) Bulk density, b) mass percentage of organic matter in soil solids, and mass percentage of c) sand and d) clay in the mineral fraction at the two research sites.

Irrigation Systems:

The North Platte site consisted of two fields, each equipped with a different irrigation system. One field was irrigated by an 11-span part-circle center pivot with XiWob sprinklers (Senninger Irrigation, Clermont, FL) installed 2.4 m above the ground every 3.2 m along the lateral. The other field was irrigated by subsurface drip lines (T-Tape) installed 0.4 m belowground every 1.5 m across the field. A full description of the SDI system can be found in Tarkalson and Payero (2008). The two irrigation systems were compared through four irrigation treatments—rainfed, shutoff after R1 growth stage, shutoff after R3 growth stage, and full irrigation. Each treatment was imposed on four plots in each field randomized in a complete block design.

The Big Springs site consisted of one field where an 8-span full-circle center pivot included two different types of water application devices. One type of device was IWob UP₃ sprinklers (Senninger Irrigation, Clermont, FL) installed 2.4 m above the ground every 2.9 m along the lateral. The other type of device was mobile drip lines (Netafim, Tel Aviv, Israel) installed on span 4 every 0.76 m along the lateral and containing 3.8 L h⁻¹ emitters every 15 cm along each drip line. The mobile drip irrigation (MDI) setup was donated and installed by Western Irrigation Supply House (Aurora, CO). The two devices were evaluated for soybean production under two residue levels (no-removal and baling of the previous year's maize residue) receiving 60% and 100% of full irrigation requirements. A rainfed treatment was also investigated. To accommodate changes in irrigation depth across treatments, the speed of the irrigation system was governed by the target amount from MDI and the sprinkler system changed rates by pulsing the sprinklers using a FarmScan 7000 VRI controller. The experimental layout is shown in Figure 2.

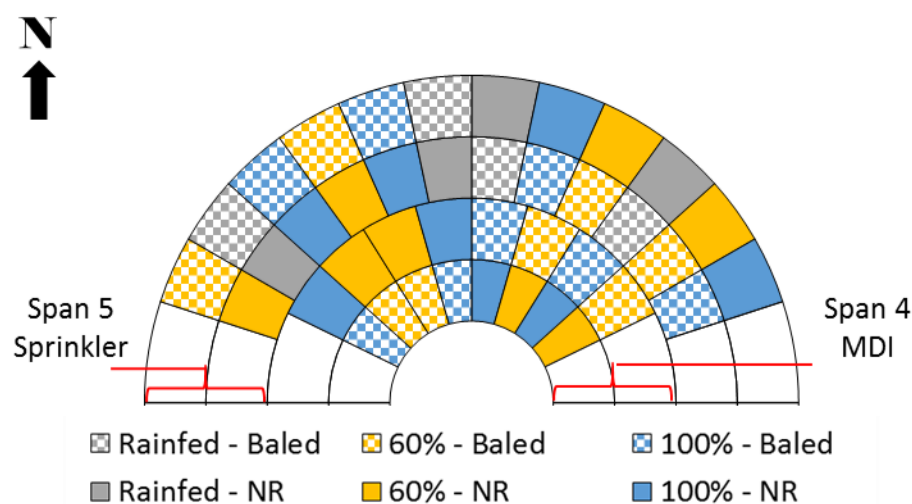


Figure 2. Experimental layout of mobile drip irrigation (MDI) versus sprinkler irrigation system under two residue levels (no-removal and baled) and three irrigation levels (0%, 60%, and 100%) at the UNL Brule Water Laboratory near Big Springs, NE.

Management Information:

At WCREC, Pioneer (Johnston, IA) maize P0339AMT was planted for both fields on 12 May 2016 at 77,000 seeds ha⁻¹ with 0.76 m row spacing following continuous maize production. Urea ammonium nitrate solution (UAN 32%) was applied on 8 April 2016 as pre-plant fertilizer at a rate of 246.6 kg ha⁻¹, and 10-34-0 ammonium polyphosphate solution was applied at planting as in-furrow pop-up fertilizer at a rate of 46.8 L ha⁻¹. Maize kernels were harvested using a combine on 10 October 2016 after reaching maturity and adjusted to 15.5% moisture content. At time of harvest, kernel samples were collected and sent to Ward Laboratory for grain N content.

On 18 May 2016, Asgrow (Monsanto Company, St. Louis, MO) soybean AG2431 was planted at BWL at 200,000 seeds ha⁻¹ with 0.76 m row spacing. Baling of the previous year's maize residue occurred on 15 April 2016. Soybean seeds were harvested using a combine on 28 September 2016 after reaching maturity and adjusted to 13% moisture content.

Soil water content was measured weekly every 30 cm to a depth of 150 cm (180 cm at WCREC) using a field calibrated CPN 503DR Hydroprobe Moisture Neutron Depth Gauge (Campbell Pacific Nuclear International Inc., Concord, CA) and used for scheduling irrigation at both sites. The full irrigation treatments were managed to prevent stored soil water from depleting below 50% of the soil's available water holding capacity (AWHC). Irrigation scheduling for both systems was based on the SDI system at WCREC and the sprinkler system at BWL. When triggered the sprinkler and SDI systems at WCREC applied 20.3 mm; whereas at BWL, the sprinkler and MDI systems applied 25.4 and 15.2 mm for full and deficit irrigation treatments, respectively.

Crop Water and Nitrogen Use Efficiencies:

Efficiency of crop production under different irrigation systems was evaluated using irrigation water use efficiency (IWUE, kg m⁻³) as proposed by Bos (1980, 1985). The IWUE index uses a rainfed yield as a baseline to account for the increase in yield associated with irrigation (Rudnick et al., 2016), and is expressed as:

$$IWUE = \frac{Y_i - Y_r}{I_i} \quad (1)$$

where, Y_i and Y_r are irrigated and rainfed yields (Mg ha⁻¹), respectively, and I_i is irrigation amount (mm).

Efficiency of N use of the treatments between the SDI and sprinkler irrigation systems at WCREC was evaluated using partial productivity factor for N (PPF_N , kg kg⁻¹) and grain N use efficiency (GNUE, kg kg⁻¹). The PPF_N and GNUE indices are expressed as:

$$PPF_N = \frac{Y}{N} \quad (2)$$

$$GNUE = \frac{GNU}{N} \quad (3)$$

where, Y is grain yield (Mg ha⁻¹), N is applied N fertilizer (kg ha⁻¹), and GNU is grain N uptake (kg ha⁻¹).

Results and Discussion:

Weather Conditions:

In 2016, lower air temperatures, lower relative humidity, and higher wind speeds were observed at BWL than at WCREC (Table 1; HPRCC, 2016). These differences led to a greater evaporative demand at BWL than at WCREC (Figure 3). Over the May-October period, the cumulative tall reference standardized reference evapotranspiration (ET_r) was 220 mm higher at BWL than at WCREC. The cumulative precipitation during this period, in contrast, was 114 mm higher at WCREC than at BWL. The majority of the in-season precipitation occurred between late May and late July. The divergence in meteorological variables between the two sites was consistent with the general east-west climatological gradient across Nebraska. The WCREC site experienced hail and severe winds on 12 August 2016, which resulted in leaf damage.

Table 1. Monthly average air temperature (T_a), relative humidity (RH), wind speed (u_3), and solar radiation (R_s) at the two research sites in 2016.

a) North Platte, Nebraska

Month	T_a ($^{\circ}\text{C}$)	RH (%)	u_3 (m s^{-1})	R_s ($\text{MJ m}^{-2} \text{d}^{-1}$)
May	14.1	69.0	2.76	21.7
June	23.2	61.6	2.72	27.3
July	23.4	72.2	2.56	22.0
August	21.8	70.8	2.35	19.5
September	17.7	67.9	2.53	15.6
October	12.6	65.6	2.23	12.5

b) Big Springs, Nebraska

Month	T_a ($^{\circ}\text{C}$)	RH (%)	u_3 (m s^{-1})	R_s ($\text{MJ m}^{-2} \text{d}^{-1}$)
May	12.8	67.7	4.25	20.5
June	22.6	57.0	3.94	25.3
July	23.3	63.3	3.36	22.1
August	21.2	64.4	2.79	19.0
September	17.3	63.6	3.33	16.8
October	12.7	56.5	3.48	13.7

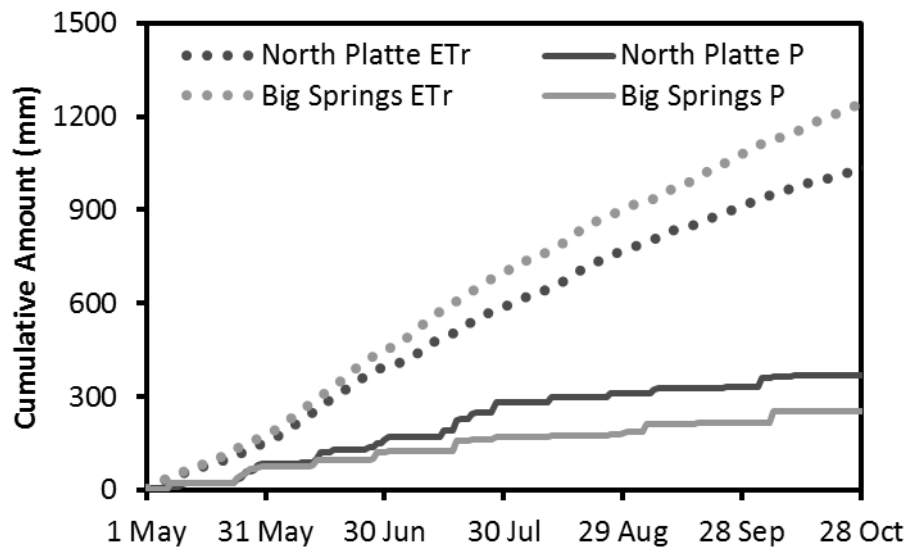


Figure 3. Cumulative tall reference standardized reference evapotranspiration (ETr) and precipitation (P) at the two research sites in 2016.

Sprinkler versus SDI:

Maize grain yield for all treatments under the SDI and sprinkler irrigation systems at WCREC are presented in Table 2. Grain yield had a positive response to irrigation for both the SDI and sprinkler irrigation systems. However, crop water response was greater under the sprinkler system with IWUE

values ranging from 2.69 to 4.46 kg m⁻³ as compared to the SDI system with IWUE values between 1.26 and 1.72 kg m⁻³. The sprinkler system had greater grain yields for each treatment as compared to the SDI system, including the rainfed treatments, which were randomized within each irrigation system's field. The rainfed treatment plots randomized within the sprinkler irrigation field were on average 0.6 Mg ha⁻¹ greater than the rainfed treatment in the SDI field. The major reason for the observed difference in treatment yields across system types was due to nonhomogeneous effects of a wind and hail storm that occurred on 12 August 2016. The SDI system's planting direction was in line with the wind direction and did not have a wind barrier and as a result experienced greater leaf damage as compared to the sprinkler system. Prior to the storm, treatments in the SDI system had slightly greater plant height (Figure 4) and leaf area index (data not shown) as compared to the sprinkler system. However, following the storm the SDI treatments root system activity decreased as compared to the sprinkler irrigation system as illustrated in the temporal total (TW) trends (Figure 5). The sprinkler irrigation system continued to remove stored soil water in the crop root zone following the storm, which resulted in greater grain yield.

Table 2. Grain yield, grain N uptake, partial productivity factor for N (PPF_N), grain N uptake efficiency (GNUE), and irrigation water use efficiency (IWUE) for the full irrigation, early shutoff at R1 and R3 growth stages, and rainfed treatments under subsurface drip and sprinkler irrigation systems.

System	TRT	Irrigation (mm)	Yield (Mg ha ⁻¹)	Grain N Uptake (kg ha ⁻¹)	PPF _N (kg kg ⁻¹)	GNUE (kg kg ⁻¹)	IWUE (kg m ⁻³)
SDI	Rainfed	0	9.2 ± 0.5	119 ± 7.2	37	0.48	-
	R1 Shutoff	20	9.5 ± 0.6	130 ± 12.9	39	0.53	1.72
	R3 Shutoff	61	10.1 ± 0.8	131 ± 9.4	41	0.53	1.55
	Full	109	10.6 ± 0.4	141 ± 6.1	43	0.57	1.26
Sprinkler	Rainfed	0	9.8 ± 0.9	134 ± 1.5	40	0.55	-
	R1 Shutoff	20	10.7 ± 1.4	145 ± 11.1	44	0.59	4.46
	R3 Shutoff	61	12.3 ± 0.8	161 ± 8.6	50	0.65	4.08
	Full	109	12.8 ± 0.9	156 ± 11.6	52	0.63	2.69

Grain N uptake was affected by irrigation treatments under both irrigation systems. In general, grain N uptake increased with irrigation depth with maximum uptake of 141 ± 6.1 and 161 ± 8.6 kg N ha⁻¹ for the full irrigation treatment under SDI and the R3 shutoff treatment under sprinkler, respectively. With a uniform N application of 246.6 kg ha⁻¹ to all irrigation treatments the resulting GNUE ranged from 0.48 to 0.65 kg kg⁻¹, with the sprinkler system having greater GNUE values as compared to SDI. Similarly, the PPF_N values increased with irrigation level for each system ranging from 37 to 52 kg kg⁻¹. The preliminary findings of this study support the well documented interaction between water and N use. Unfortunately, with uneven effects of wind and hail damage across the two irrigation systems a fair system comparison analysis was not possible. Additional analysis will be conducted following the second study year, including evapotranspiration, soil water uptake dynamics, among others, which will assist in understanding the differences in system performance in terms of grain yield, irrigation water use efficiency, economics, and environmental impact.

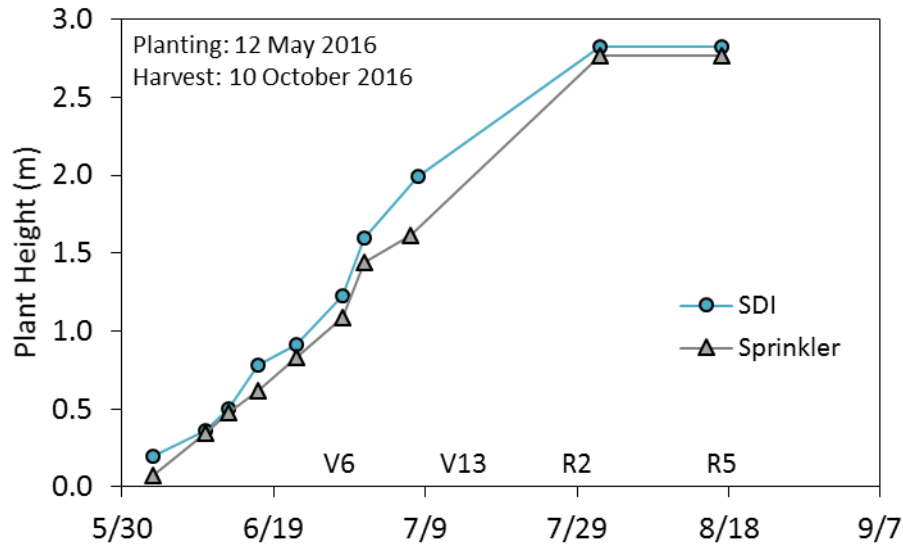


Figure 4. Comparison of average plant height (m) between the subsurface drip irrigation (SDI) and center pivot sprinkler irrigation (Sprinkler) systems.

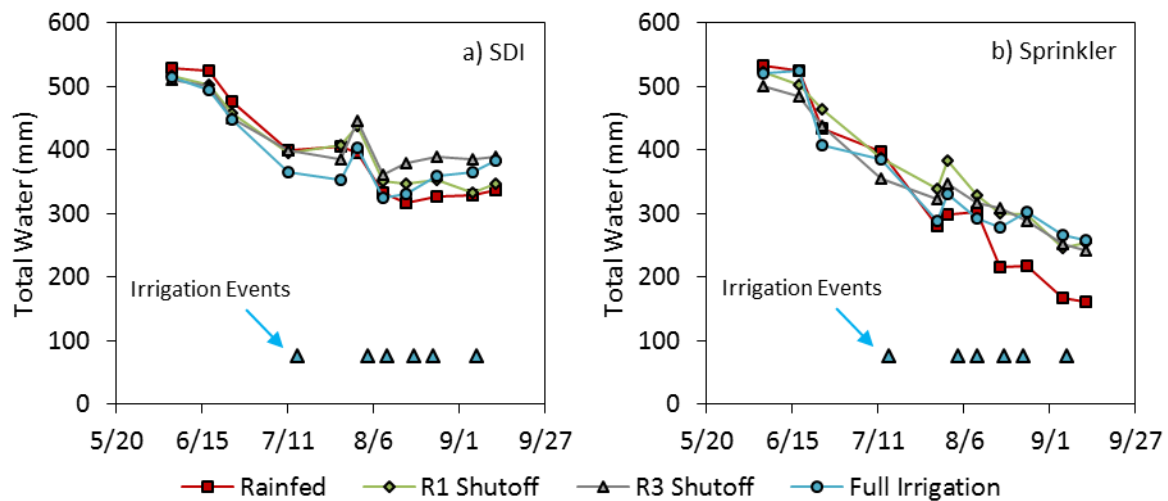


Figure 5. Seasonal trend in total water (mm) in the 1.80 m soil profile for the full irrigation, early shutoff at R1 growth stage, early shutoff at R3 growth stage, and rainfed treatments under a) subsurface drip (SDI) and b) sprinkler irrigation systems. Irrigation events are noted.

Sprinkler versus MDI:

Soybean grain yield increased with irrigation depth for both the MDI and sprinkler devices. Seasonal irrigation was 168 and 279 mm for the deficit and full irrigation treatments, respectively. The rainfed treatment had yields of 3.38 ± 0.73 and 3.53 ± 0.35 Mg ha⁻¹ under baling and no removal of residue conditions, respectively (Table 3). Under baling conditions with full irrigation requirement the MDI device had slightly greater grain yield of 5.28 ± 0.28 Mg ha⁻¹ as compared to the sprinkler device of 5.19 ± 0.35 Mg ha⁻¹. However, under deficit irrigated conditions the sprinkler device with no residue removal had 5.4 to 10.2% higher yields than the other treatments and had the greatest IWUE value of 0.95 kg m⁻³. The full irrigation and no residue removal treatment under sprinkler irrigation had the

greatest overall grain yield of $5.35 \pm 0.57 \text{ Mg ha}^{-1}$; however, it had one of the lower IWUE values of 0.65 kg m^{-3} . Irmak et al. (2014) reported similar IWUE values for soybean under SDI in central Nebraska. Their values ranged from 0.46 to 1.04 kg m^{-3} in 2007 and 0.05 to 0.29 kg m^{-3} in 2008.

Table 3. Grain yield and irrigation water use efficiency (IWUE) for the irrigation (full, deficit, and rainfed) and residue (baling and no-removal) treatments under mobile drip and sprinkler irrigation devices.

System	Residue	Irrigation	Irrigation (mm)	Yield (Mg ha^{-1})	IWUE (kg m^{-3})
-	Baling	Rainfed	0	3.38 ± 0.73	-
	No-Removal	Rainfed	0	3.53 ± 0.35	-
MDI	Baling	60% of Full	168	4.66 ± 0.44	0.76
		Full	279	5.28 ± 0.28	0.68
	No-Removal	60% of Full	168	4.86 ± 0.09	0.79
		Full	279	5.18 ± 0.59	0.59
Sprinkler	Baling	60% of Full	168	4.65 ± 0.65	0.76
		Full	279	5.19 ± 0.35	0.65
	No-Removal	60% of Full	168	5.12 ± 0.56	0.95
		Full	279	5.35 ± 0.57	0.65

Trends in total water (TW) in the 1.50 m soil profile for all treatments are presented in Figure 6. All treatments and soil layers started at or near field capacity. As expected, greater seasonal depletion in stored water occurred for the deficit and rainfed treatments as compared to the fully irrigated treatments. No obvious trends were observed across system type or residue treatments; however, this could be slightly masked by modest differences in soil physical properties across the study area. Integrating changes in stored soil water into a water balance for ET determination will allow for a better assessment of treatment hydrologic differences. This analysis will be performed following the second study year.

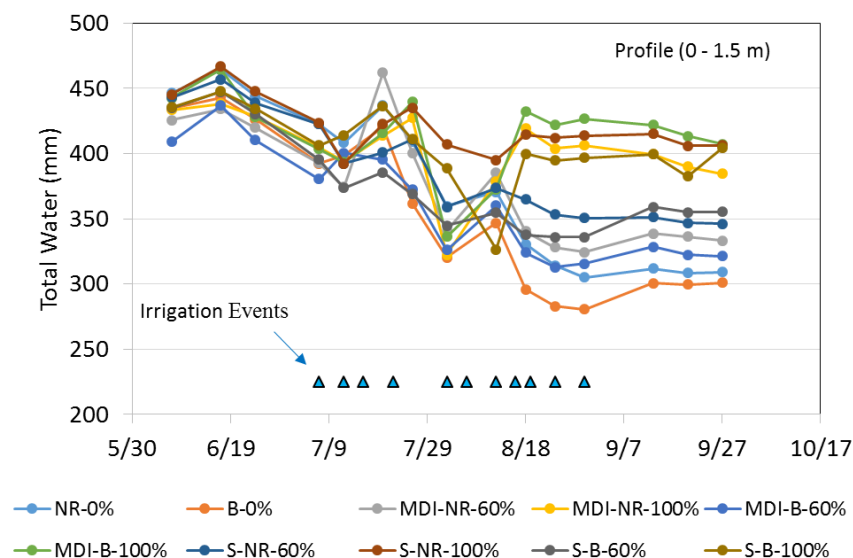


Figure 6. Seasonal trend in total water (mm) in the 1.50 m soil profile for the irrigation (full, deficit, and rainfed) and residue (baling and no-removal) treatments under mobile drip and sprinkler irrigation devices. Irrigation events are noted.

Summary and Scholarly Output:

This grant supported research at two sites: University of Nebraska-Lincoln (UNL) West Central Research and Extension Center (WCREC) in North Platte, NE and UNL's Brule Water Resources Field Laboratory (BWL) near Big Springs, NE. A system performance assessment under different irrigation treatments was carried out between SDI and sprinkler irrigation at WCREC and between MDI and sprinkler irrigation at BWL. Information derived from this study will aid in our understanding of the performance of various irrigation management strategies under different irrigation system types, which will strengthen crop, hydrologic, and economic models. This document reports preliminary findings of the research projects. Further analysis will be performed following the second study year.

This research also provided a platform to evaluate the performance of various irrigation technologies. One manuscript is currently under review in a peer-reviewed journal.

References:

- Bos, M.G. 1980. Irrigation efficiencies at crop production level. *ICID Bull.*, 29(2): 18-25, 60.
- Bos, M.G. 1985. Summary of ICID definitions of irrigation efficiency. *ICID Bull.*, 34(1): 28-31.
- Ferguson, R.B. 2015. Groundwater quality and nitrogen use efficiency in Nebraska's Central Platte River Valley. *J. Enviro. Qual.* 44(2): 449-459.
- HPRCC. 2016. Data Retrieval. High Plains Regional Climate Center. Retrieved from <http://hprcc6.unl.edu/cgi-hpcc/dr3.cgi>
- Irmak, S., L.O. Odhiambo, W.L. Kranz, and D.E. Eisenhauer. 2011. Irrigation efficiency and uniformity, and crop water use efficiency. University of Nebraska-Lincoln Extension Circular EC732.
- Irmak, S., J.E. Specht, L.O. Odhiambo, J.M. Rees, and K.G. Cassman. 2014. Soybean yield, evapotranspiration, water productivity, and soil water extraction response to subsurface drip irrigation and fertigation. *Trans. ASABE* 57(3): 729-748.
- Lamm, F. 2015. Cotton, tomato, corn, and onion production with subsurface drip irrigation – A review. Proceedings of the 2015 ASABE/IA Irrigation Symposium: Emerging Technologies for Sustainable Irrigation, Long Beach, CA, November 10-12, 2015.
- NRCS. 2005. Cozad - Official Series Description. Natural Resources Conservation Service. Retrieved from https://soilseries.sc.egov.usda.gov/OSD_Docs/C/COZAD.html
- NRCS. 2006. Kuma - Official Series Description. Natural Resources Conservation Service. Retrieved from https://soilseries.sc.egov.usda.gov/OSD_Docs/K/KUMA.html
- NSCO. 2017. Mesonet by NSCO. Nebraska State Climate Office. Retrieved from <https://mesonet.unl.edu>
- PRISM Climate Group. (2014). 1981-2010 Average Annual Precipitation. Oregon State University. Retrieved from <http://www.prism.oregonstate.edu/normals/>
- Rudnick, D.R., V. Sharma, G.E. Meyer, and S. Irmak. 2015. Using fuzzy logic to predict and evaluate the impact of temporal and spatial precipitation on rainfed maize and soybean yields in Nebraska. *Trans. ASABE* 58(5): 1215-1229.
- Rudnick, D.R., S. Irmak, R. Ferguson, T. Shaver, K. Djaman, G. Slater, A. Bereuter, N. Ward, D. Francis, M. Schmer, B. Wienhold, and S. van Donk. 2016. Economic return versus crop water productivity of maize for various nitrogen rates under full irrigation, limited irrigation, and rainfed settings in south central Nebraska. *J. Irrig. Drain. Eng.* 142(6).
- Schneekloth, J.P., N.L. Klocke, D.R. Davison, and J.O. Payero. 2006. Furrow irrigation management with limited water. *App. Eng. Agric.* 22(3): 391-398.
- Tarkalson, D.D. and J.O. Payero. 2008. Comparison of nitrogen fertilization methods and rates for subsurface drip irrigated corn in the semi-arid Great Plains. *Trans. ASABE* 51(5): 1633-1643.

Energy-water reduction and wastewater reclamation in a milk processing facility

Basic Information

Title:	Energy-water reduction and wastewater reclamation in a milk processing facility
Project Number:	2016NE288B
Start Date:	3/1/2016
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	1
Research Category:	Water Quality
Focus Categories:	Water Use, Wastewater, Treatment
Descriptors:	None
Principal Investigators:	Bing Wang, Rolando A. Flores, Jayne Stratton

Publications

There are no publications.

Energy-water reduction and wastewater reclamation in a milk processing facility

Basic Information

Title:	Energy-water reduction and wastewater reclamation in a milk processing facility
Project Number:	2016NE288B
Start Date:	March 1, 2016
End Date:	February 28, 2017
Funding Source:	104B
Congressional District:	Nebraska US District 1
Research Category:	Water Quality
Focus Category:	Water use, wastewater, treatment
Descriptors:	Dairy food processing, wastewater, water reconditioning, water reuse, Microbial safety
Principal Investigator(S):	Bing Wang, Rolando Flores and Jayne Stratton

Publications

There are no publications at this time.

2016 - 2017 Annual Report

Project # 2016NE288B

Energy-water reduction and wastewater reclamation in a milk processing facility

May 2017

Principal Investigator: Bing Wang, Ph.D.
Assistant Professor
Department of Food Science and Technology
University of Nebraska-Lincoln

Co-Investigator: Rolando A. Flores, Ph.D.
Professor & Head, Department of Food Science and Technology
Director, The Food Processing Center
University of Nebraska-Lincoln
Current as Dean & Chief Administrative Officer, College of
Agricultural, Consumer and Environmental Sciences
New Mexico State University

Jayne E. Stratton, Ph.D.
Research Associate Professor
Department of Food Science and Technology
The Food Processing Center
University of Nebraska-Lincoln

Reporting Period: March 1, 2016 through February 28, 2017

Financial Support: USGS

Participants: Postdoctoral Fellow Graduate Student
Yulie Meneses* Carly Rain Adams
Current as Research Assistant Professor
Department of Food Science and Technology
University of Nebraska-Lincoln
**Partially supported by this funding*

INTRODUCTION

Project Summary

Water, the truly essential element of life, is a luxury for most. However, it cannot be seen as a right for all. According to The United Nations, over 780 million people lack access to clean water daily. As the population insistently goes up, the stress placed on resources will strengthen. To create and enforce our sustainable food system, we must take a frontline stance on creating new methods and technologies for process optimization and resource reduction. Together this will create a secure food system.

The energy-water-food nexus is the inseparable connection linking water and energy consumed for food supply. We are faced with a unique opportunity to co-manage these resources, as conservation of one is directly related to the conservation of its counterpart (Gulati, Jacobs, Jooste, Naidoo, & Fakir, 2013). Therefore, immediately facing this critical challenge, will lead to tangible impacts on the water and energy crisis testing our food system today. Determining the role of water and energy in the food industry has proved to be an ideal starting point for reducing the distance between process productivity and resource efficiency.

Objectives

The overall goal of this research is to locate opportunities that lend themselves to both water-energy reduction and recondition wastewater. This research was conducted in a medium-sized fluid milk processing facility as a show case example. The long term goal and expected impact of this research are to transform our findings into a set of industry-wide guidelines that will create a culture of water and energy conservation.

To reach this long-term goal, the project was portioned into two phase; four specific objectives were developed:

Phase 1:

1. To determine the baseline quantities of water and energy consumed by a medium-sized dairy plant
2. To locate potential areas for source reductions

Phase 2:

3. To develop a risk assessment framework for the reuse of cleaning agents in CIP operations
4. To identify data gaps for the development of a risk assessment study on the reuse of chemical agents

RESEARCH PROGRAM

Phase 1

Methods

The first step was to understand the inner workings of the plant. This dairy plant produces, on average 7,218 gallons of finished milk per day. To best understand this, 10 plant visits were made, and a process flow diagram was developed. Visits were made more consistently at the start, to develop methodology and to learn details of production. An additional 12 visits were made to collect quantitative water and energy data. Figure 1 shows the path of milk from raw to finished product. After milking, raw milk is transported from farm to processing facility. Upon arrival, all raw milk undergoes separation via centrifugation. This process allows for raw cream separation out from the whole milk and set aside. Raw skim milk is pumped into either tank 1, 2, or 3. The standardization of fluid milk, as well as the addition of any new ingredients, takes place in the liquefier. All processed milk will undergo High Temperature Short Time pasteurization and homogenization. After milk is heat treated it is sent to one of the five specified tanks. From here the pasteurized milk will be packaged in either bottles or pouches

and prepped for transportation. Developing this process flow allowed for an understanding of process inputs; milk, natural gas, and electricity.

Part 1: Process Flow

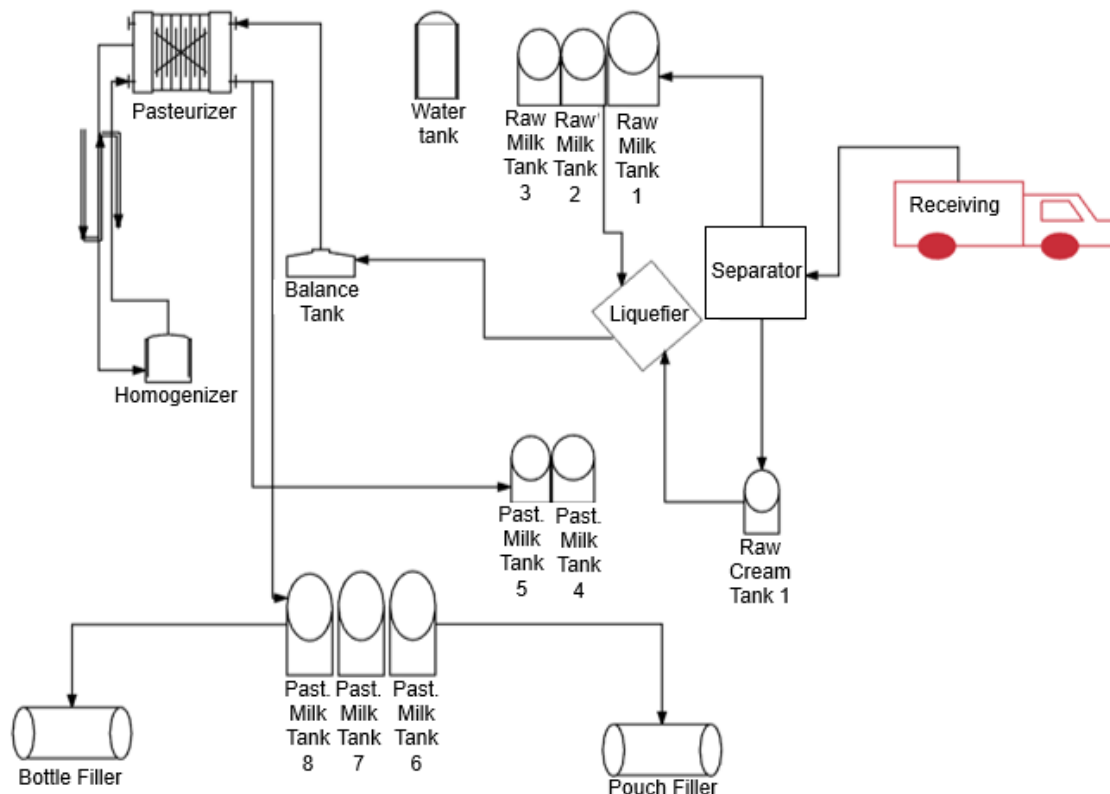


Figure 1: Process flow diagram of fluid milk processing in a medium sized dairy plant

Part 2: Energy Consumption

The dairy processing facility consumes energy in two forms: natural gas and electricity. The main form of energy consumed by the fluid milk processing plant is electricity. The boiler is the sole consumer of natural gas. Both forms of energy were analyzed by the consolidation of billed usage readings. These allowed for monthly usage determination.

While it was understood that the sole user of natural gas was the boiler, it was unknown how the electricity was distributed. A collaborative partnership between a state electrical company and the researchers was possible. As the fluid milk processing facility was a customer of the electrical plant, they qualified for energy inquiry and assistance. This collaboration allowed for the use of the Ted Pro 400. Two certified electricians installed this commercial 3-phase electricity monitor in the plant. This meter allowed for monitoring of multiple circuits throughout the processing plant. This would measure kWh consumption of multiple points within the processing room. Electrical readings were uploaded to the online record keeping devices each

hour. This also allowed for the division of total electrical consumption into various processing units. Figure 2, shows a visual representation of the installed energy meter.

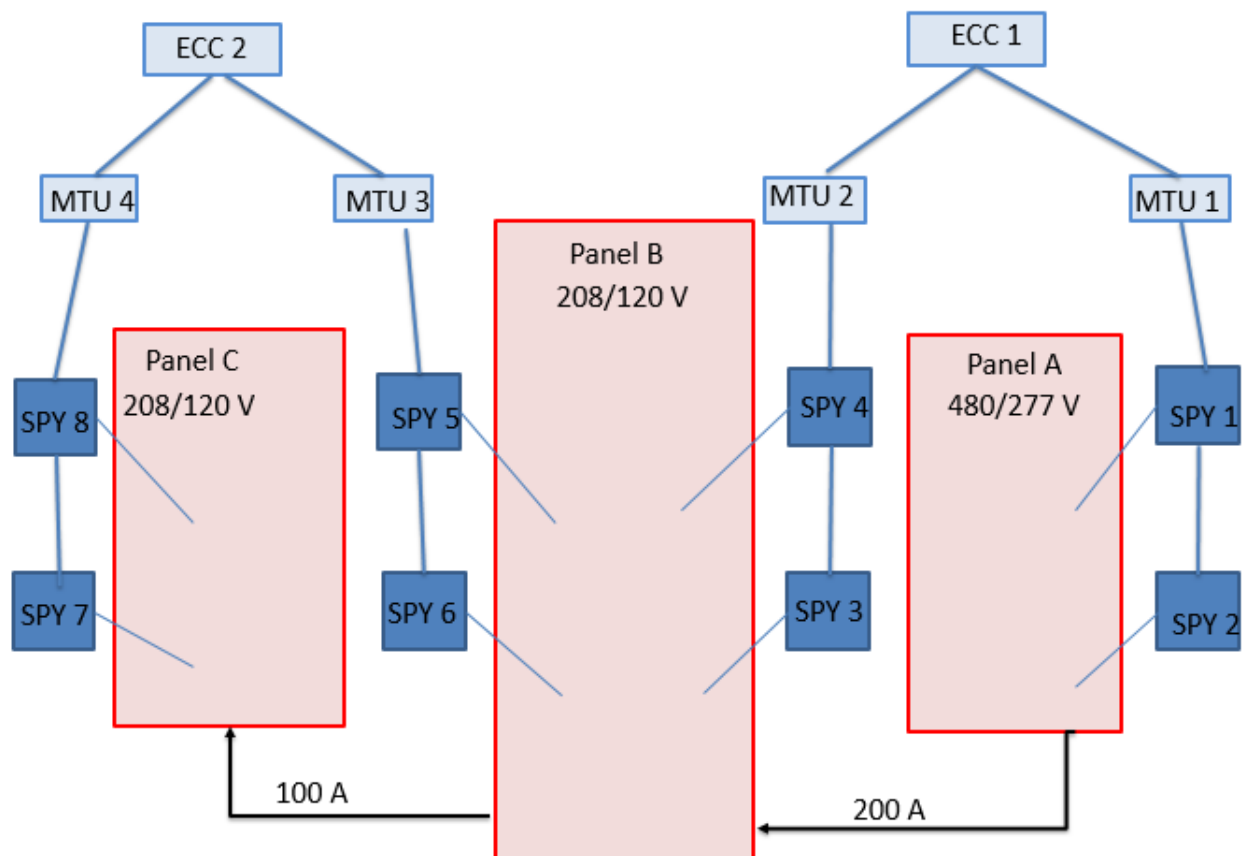


Figure 2: Diagram of installed 3 phase meter; TED Pro 400

The TED Pro 400 was designed to have two energy control centers (ECC). The two ECCs receive raw energy use data from the measuring transmitting units (MTU). The ECC will interpret data to generate cost data. Each ECC will send data through a wireless connection to the online support system. Each MTU measure the energy consumption. Each MTU can measure 16 circuits via the two SPYDERS at 8 circuits each. Panel A is the main panel. Panel B is a sub panel of Panel A, and is fed from Panel A. Panel C is a sub panel to panel B, and is fed from Panel B.

Part 3: Water Consumption

Water usage data was collected through bill consolidation. This gave monthly consumption volumes for the plant. To determine where this water was going, and when it was being consumed, inline meters were purchased (Dwyer Multi-Jet Water Meter w/ Pulsed Output, WMT2-A-C-04, 1" NPT, 50 GPM, Brass Body). Both meters were designed for inline installation. The pipe in the boiler feed tank was sliced, and the inline meter was incorporated. The second meter was installed near the main city provided water meter. The second meter would give data,

in gallons, of total water consumption while the first meter would indicate gallons consumed by the boiler. Both meters were connected to iMONNIT, an online data collection, and display system. Both meters tallied water consumption hourly, due to their connection to a pulse monitor. Therefore, water consumption variation throughout the day was observed. It was determined that this plant operates on two shifts. The first shift, processing shift, takes place between 03:00 and 14:00. The second shift, cleaning shift, begins when processing is complete and will go until 23:00. These time frames held some variation processing loads vary with demand.

Part 4: Wastewater generation

The processing plant kept sporadic records of wastewater generated. It was hypothesized that the contents of the wastewater were; milk, water, and cleaning chemicals. The wastewater generated had two destinations, once the tanker was more than half full it was either sent off to the fields, to be directly land applied or disposed into a designated lagoon. The water settles here and then is pumped for irrigation purpose. When the truck is sent to the lagoon, it passes over a scale. However, the days where the wastewater is directly land applied, the truck is not weighed. Records for wastewater were collected throughout the project.

Part 5: Mass balance and sampling

This plant's cleaning process operates on two cleaning in place procedure (CIP) and additional cleaning out of place operations. Both cleaning in place systems are made up of four steps.

Step 1: Rinse water

Step 2: Caustic solution + fresh water

Step 3: Alkaline solution + fresh water

Step 4: Sanitization solution+ fresh water

The first CIP system, Figure 3A, was designed for automatic cleaning of the processing equipment and the first five tanks. The second system, Figure 3B, is the automated cleaning of the last three finished milk storage tanks and the pouch filler. Stage one involves automated flushing of the pasteurizer and homogenizer with fresh cold water. Each stage will start at the star, seen in figure 3A. An operator uses a hose containing hot water to remove any excess product in tanks 1-5. This rinse water is discarded to the floors. Fresh water is added to the balance tank, and for the remaining stages water and specific cleaning solution go into the balance tank, flow through the pasteurizer and homogenizer and then move to tank 5. Once the water has been cycling in tank 5 it returns to the balance tank. Additional water is added to the tank and the cycle repeats until all five tanks are done.

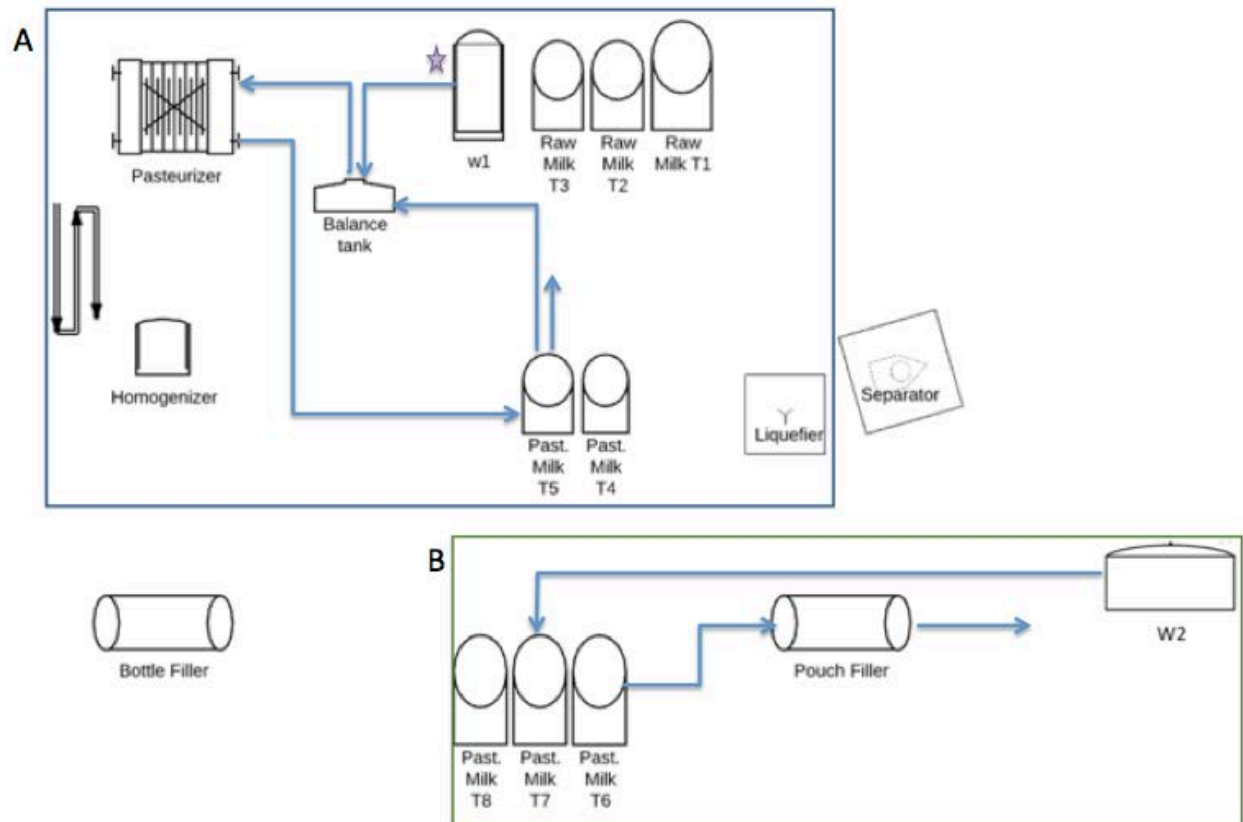


Figure 3: Cleaning in Place operations for fluid milk processing facility.

To perform a mass balance of the water used during the cleaning in place operations, Fuji Ultrasonic meters were utilized. These meters measured flow rate and total gallons of water as it flowed through the designated pipe. Each meter was calibrated based on pipe dimensions. Along with the flow meters, manual measurements of flow were also taken. The mass of water consumed during the total cleaning in place systems were monitored.

Results

Electricity

Figure 4 shows the change in electricity billed monthly. Data used in this chart was compiled from billed utility data. This data shows that consumption of electricity varies throughout the year. This can be due to increased production during school years. Production ramps up to produce milk for school lunch. The monthly consumption of electricity ranges from 12,968-24,657 kWh. The local power company installed an hourly kWh meter. This meter showed differences in electrical use during different stages of operation. Therefore, figure 5 shows the amount of electricity consumed during the two stages of production: processing and cleaning. On average, processing is the largest consumer of electricity. The electrical consumption during the cleaning is 25% of the total electricity consumed.

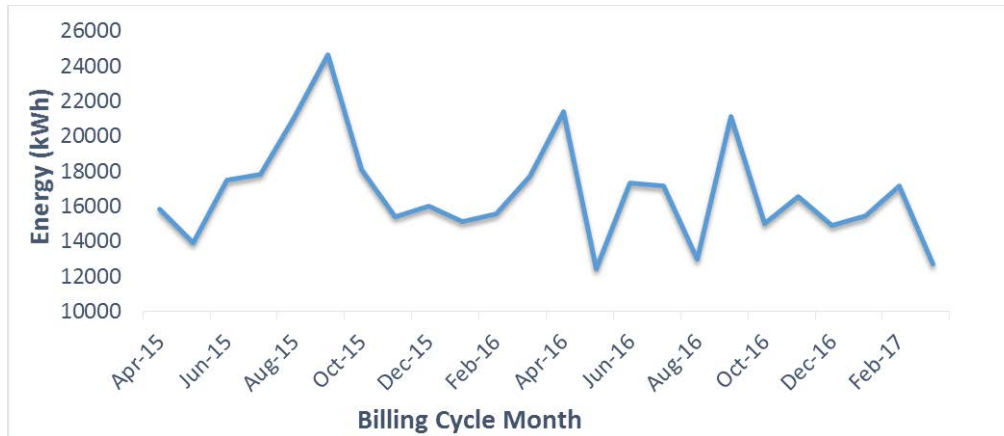


Figure 4: Amount of electricity consumed per month

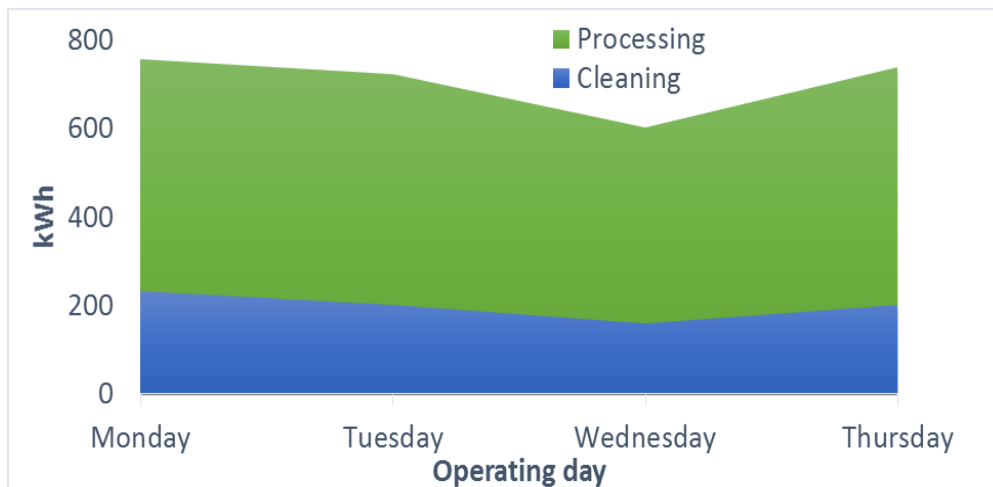


Figure 5: Amount of electricity consumed during processing vs. cleaning during stages of a fluid milk processing facility.

Using The TED Commander three phase meters, the electricity consumption for processing units was found. Figure 6 shows 89% of the total electricity consumed during production. The range of therms consumed by a milk processing plant was 1340-3051. Figure 7 indicates the monthly consumption base on the plant's bills; the August peak could be due to increased production.

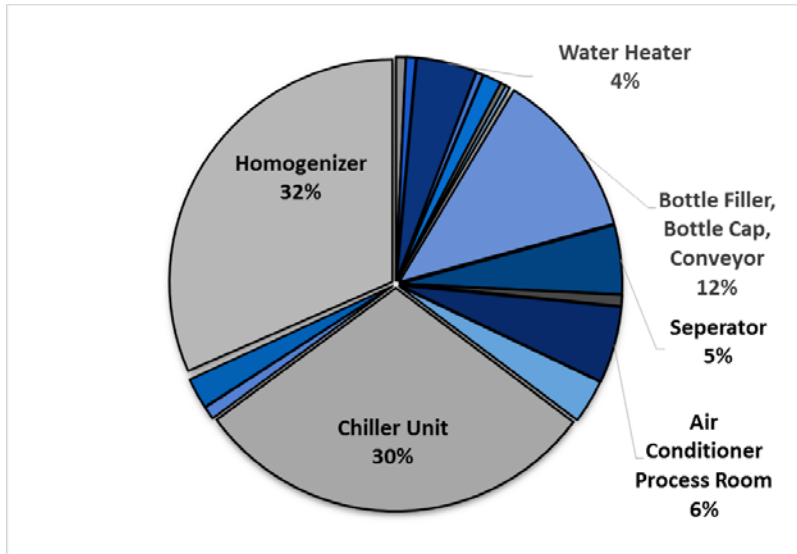


Figure 6: Percentage of electricity consumption by various units per day

Natural Gas



Figure 7: The Amount of Natural Gas Consumed per Month

Water

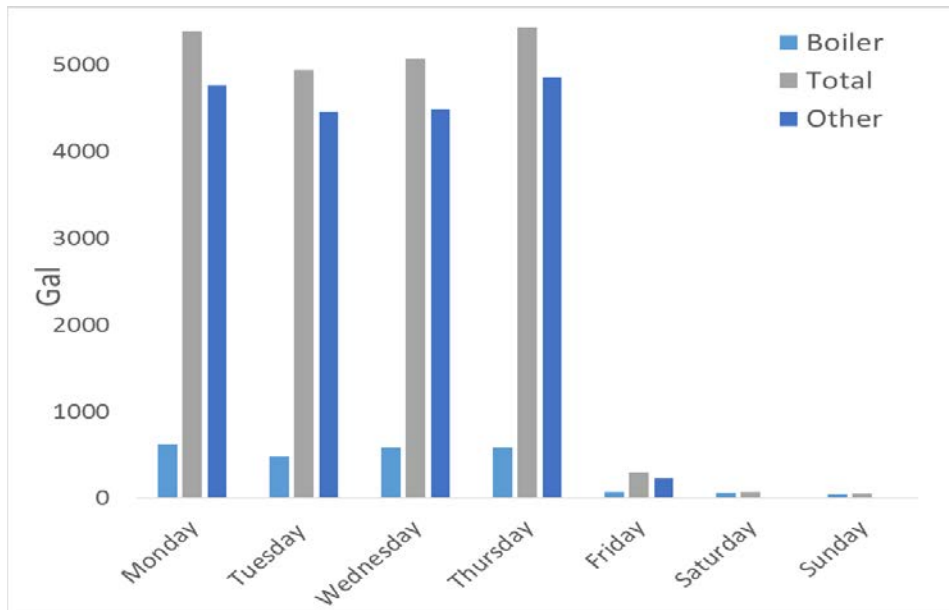


Figure 8: The Amount of water Consumed by the boiler

The two inline meters' data was combined, and the amount going into their boiler feed tank was determined. The boiler, which is processed through natural gas, makes up 11% of the total water consumption. The remainder of the water (89%) is processed through electricity. This water is used to cool the homogenizer, clean facilities, and operate office areas. Based on time recordings of the total water brought into the plant. It was determined the amount of water consumed during the two different stages of production: processing and cleaning. The amount consumed during cleaning, 53%, can be seen in figure 9. Thus, it was concluded that the cleaning process consumed the greater amount of water. This stage offered the greatest opportunities for water reduction. Therefore, the cleaning stage will be the focus of the treatment recommendations.

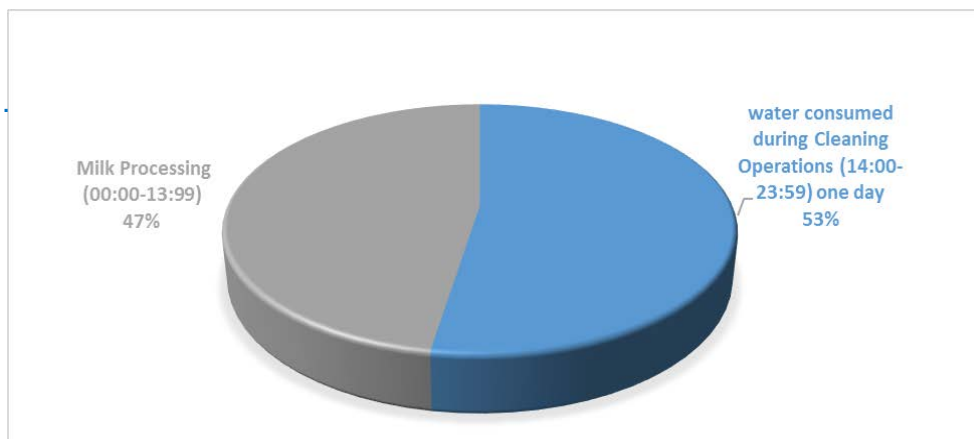


Figure 9: Percentage of water consumed during a production day

A material balance of the cleaning operations showed the amount of water used for each step. The hose water and homogenizer are the sources of water lost which are not part of the automated cleaning. The 12% of water lost through the homogenizer is directly released to the floor, and it is used for cooling. Figure 10, shows the volume as a percentage of water lost through the cleaning procedures.

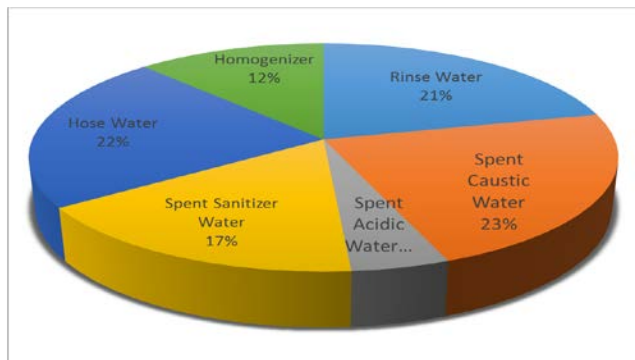


Figure 10. Percentage of water consumed during cleaning procedures

Wastewater

The wastewater was thought to be made of water, milk, and spent chemicals; figure 11 shows the volume of wastewater generated in a monthly base. The water quality characteristics of the wastewater are displayed in Table 1. Samples were collected and analyzed from the cleaning process of fluid milk processing. Biological Oxygen Demand (BOD) determines the relative strength of the wastewater. It is measured to establish the concentration of organic matter in the sample. BOD measures oxygen demand by all microorganisms in the samples. The chemical oxygen demand (COD) was measured as an indication of the concentration of organic matter. Total suspended solids (TSS) measure some solids that would be trapped during wastewater treatments. These results, indicate that the initial rinses and the wastewater contain high residues of milk and consequently high levels of COD, BOD and TSS are observed. In the other cleaning streams for caustic, acid and sanitizer these values are significantly lower. Considering water quality and the volumes produces during cleaning operations, these streams represent potential opportunities for reuse after appropriate treatment.



Figure 11: Volume of wastewater generated per Month.

Table 1: Quantitative Analysis of Wastewater

Quality Measurements of spent solutions used during the Cleaning-In-Place Systems							
Parameters	Rinse Cleaning Water, tanks	Caustic Cleaning Water ,tanks	Acidic Cleaning Water, tanks	Sanitizer Cleaning Water, tanks	Principal Cleaning Water	Truck Wastewater	Caustic Cleaning Water, Past/Hom
BOD (mg/L)	25,110	1,230	51	183	-	4,950	1,230
Conductivity (uS/cm)	1,170	51.2	46.9	1,020	4.19	7.29	45.5
pH	7.46	13.3	1.25	4.27	12.1	12.3	13.6
TSS (mg/L)	11,606	19	*1.00	*1.00	11	2,088	924
COD (mg/L)	29,610	-	11.0*	829	335	20,120	4,310
Total Kjeldahl Nitrogen	28.8	0.48	1.09	0.203	0.222	36.6	15.5
Total Kjeldahl Phosphorus	15.5	1.05	166	11.4	5.79	73.6	94.7

* below method detection limit

To determine the amount of each utility used for the production of one gallon of pasteurized milk, the results reported earlier were combined with the production reports. Thus, the amount of natural gas, electricity, and fresh water consumed to make one gallon of milk are reported in Table 2. For every gallon of milk produced, 0.13 kWh, 0.01 Therms, and 0.87 gallons of fresh water are required. For an average production day 938 kWh, 72 Therms, and 6280 gallons fresh water are consumed.

Table 2: The amount of utilities consumed per gallon of finished milk

Fluid Milk Processing Consumption		
Utility	Unit	Amount used
Electricity	kWh/ gal. finished milk	0.13
Natural Gas	Therms/gal. finished milk	0.01
Fresh Water	gal water /gal. finished milk	0.87
Wastewater	lb. wastewater/gal. finished milk	5.11

Phase 2

Methods

A conceptual model was designed (see Figure 12) to describe the effect of cleaning operations in the overall risk contamination of pasteurized fluid milk with *Listeria monocytogenes*. The model was developed with the scope to cover the same steps described earlier in this report for the pasteurization of fluid milk. During the process, the efficacy of cleaning-in-place (CIP) operations in the receiving and pasteurized tanks are considered. To capture the effect of the cleaning efficiency in the overall risk, equation 1, 2 and 3 were developed to determine the efficiency ratio (*ER*) and efficiency factor (*EF*), respectively.

$$ER = \frac{p_{aft}(1-p_{bf})}{p_{bf}(1-p_{aft})} \quad \text{Eq. 1}$$

$$EF = \log_{10} c_{aft} - \log_{10} c_{bf} \quad \text{Eq. 2}$$

Where p_{bf} and p_{aft} are the probability of a randomly selected sample being positive for *Listeria monocytogenes* calculated as the ratio of number of positive samples out of the total number sampled, before and after CIP washing, respectively. c_{bf} and c_{aft} are average concentrations among all the positive samples before and after CIP washing.

$$TC = \frac{\sum_1 \frac{\text{Binomial}(\frac{a_{tank}}{a_{coupon}}, p_{24h})}{a_{coupon} * c_{24h}}}{\sum_1 \frac{\text{Binomial}(\frac{a_{tank}}{a_{coupon}}, p_0)}{a_{coupon} * c_0}} \quad \text{Eq. 3}$$

Where a_{coupon} is the total surface area of the coupons used in the experiment; a_{tank} is the total contact surface of the equipment during processing procedure, which varies depending on the supply need and capacity; p_0 and p_{24h} are the probability of a randomly selected coupon being *Listeria* positive at time 0 and 24 h; and c_0 and c_{24h} are average concentrations among all the positive coupons at time 0 and 24 h.

Important Findings

Identifying data available required to populate the model was the first step. From literature review, it is possible to determine microbial quality of milk throughout the process. However, little information is available about the microbial contamination before and after CIP operations, and none data was available about the impact of the reuse of alkaline and acidic solutions in the cleaning efficiency. Therefore, a significant data gap was identified for this stage of the model.

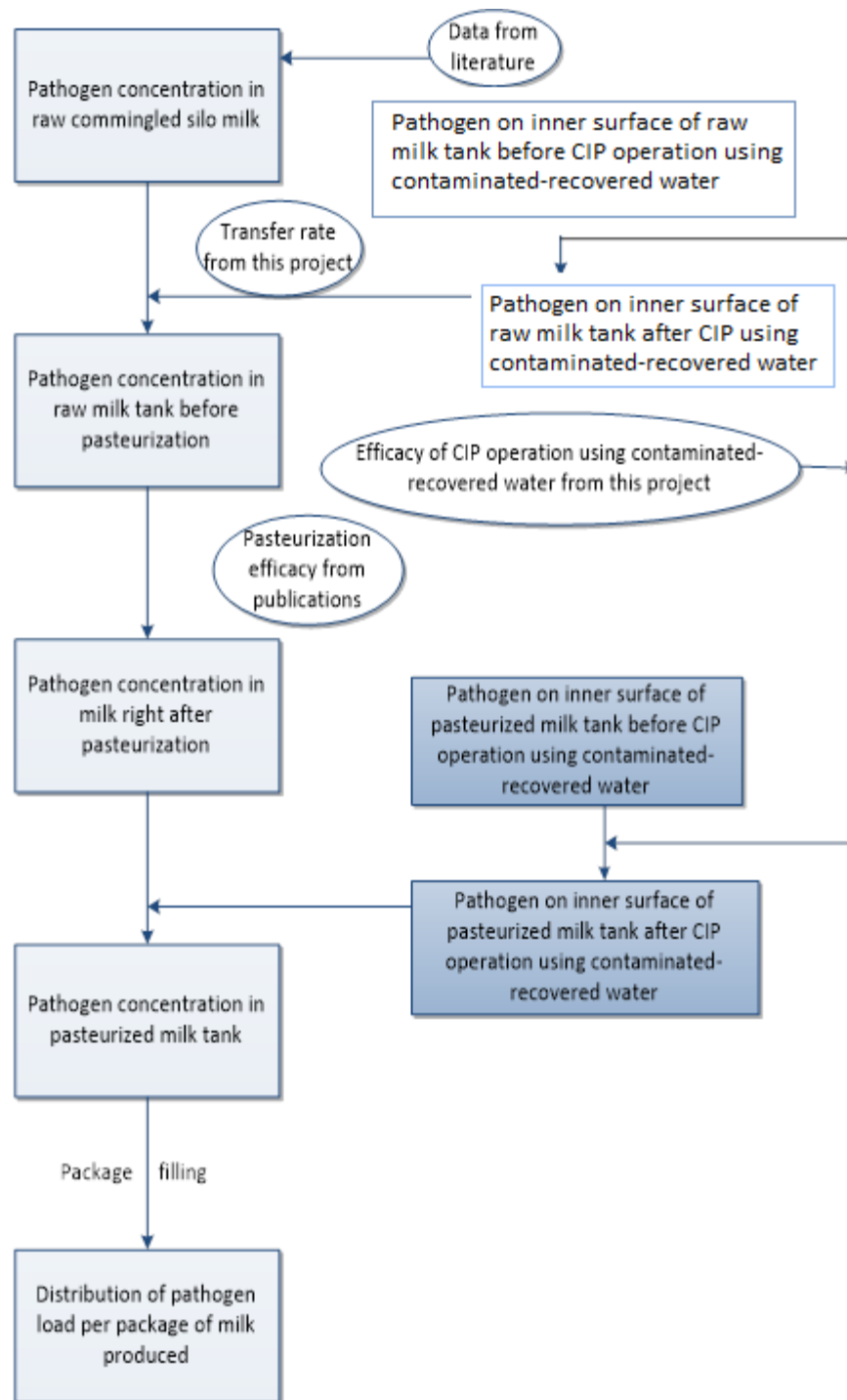


Figure 12. Flow diagram of the risk assessment conceptual model of *Listeria monocytogenes* contamination in packaged fluid milk when reconditioned cleaning solutions are used in the CIP

Table 3 describes the data that are currently available in the literature related to the reuse of alkaline and acidic solutions (cleaning agents). It can be observed that most of the research has focused on defining the chemical quality of recovered solutions. However, the cited studies do not demonstrate the cleaning efficiency, of the recovered solution, in cleaning operations. To populate the model, data on the microbial load before and after the application of the recovered cleaning agents are required.

Table 3. Summary of data gaps identified for the reuse of cleaning agents in Cooperation

Current limitation of evidence collection	Corresponding data gap	Next Steps	Priority
Cleaning efficiency of reconditioned stream, based only on chemical characteristics	Cleaning efficiency proved on the removal of microbial contamination	Develop experiments that allow data collection on chemical and microbial quality (concentration and prevalence)	+++
Limited data on the number of times a reconditioned stream can be recycled	Determination of the maximum number of times a reconditioned stream can be recycled without compromising cleaning efficiency	Conduct experiments on the reuse of the reconditioned streams	+++
Cleaning efficiency reported only for the acidic solution permeate	Cleaning efficiency of alkaline, acidic, and sanitizer solution alone and in combination	Evaluate cleaning efficiency in all streams, individually and combined	++

Conclusion

An implementation of change to reach higher levels of source reduction is multiphase. Reconditioning treatments are the largest and most tangible method for reuse and recovery of spent wastewater. However, the culture of the plant is a key factor. It is important to motivate plant operators to use water consciously. They must have a passion for the cause. After all, treatment options will fail if the operators do not care about water recovery and source reduction. This desire to help should come from a desire to be a good steward of the resource and for the advancement of the economic future of the company.

The nexus of energy and water has been demonstrated with the detailed report on utility consumption. Important savings can be achieved by implementing recirculation systems especially in those process that require hot water.

Cleaning operations are the main consumers of water/energy and also generators of wastewater. These streams represent an opportunity for water reconditioning and reuse. To promote the reuse of reconditioned streams, it is critical to develop a risk assessment model.

The main finding in the conceptual model was the identification of key data gaps, which will serve as a guide for future research.

References

1. United Nations. 2013. Water Cooperation: Facts and Figures. United States Educational, Scientific and Cultural Organization, 2013. Available at: <http://www.unwater.org/water-cooperation-2013/get-involved/campaign-materials/water-factsheets/en/>
2. Gulati, M., Jacobs, I., Jooste, A., Naidoo, D., & Fakir, S. (2013). The Water–energy–food Security Nexus: Challenges and Opportunities for Food Security in South Africa. *Aquatic Procedia*, 1, 150–164.

Information Transfer Program Introduction

The Nebraska Water Center has a long and proud tradition of actively pursuing a widely diverse information transfer program. USGS funding underwrites a range of public and professional information and educational efforts, including: (1) four quarterly issues of the Water Current newsletter, which are mailed to more than 2,800 subscribers and appears as an online pdf; (2) updating and reprinting Water Center fact sheets and informational brochures; (3) more than 20 press releases reporting on water-related research, education, event and outreach programming from across the University of Nebraska or promoting the NWC and WSL; (4) direct support for two internet web sites and Facebook, Twitter and YouTube accounts; (5) publicity and supporting materials for an annual water law conference, public lecture series, water symposium, and water and natural resources tour; (6) coordinating UNL Extension's largest public program and student recruitment event of the year at Farm Progress Co.'s Husker Harvest Days farm show; (7) other publications and events; and (8) publication and distribution of full-color annual reports.

Since 2010 (??) NWC has been an integral part of the Daugherty Water for Food Global Institute, a global initiative involving all University of Nebraska water faculty and staff with a mission of greater global agricultural water management efficiency. NWC and DWFI co-located to offices at the University of Nebraska's new "Nebraska Innovation Campus" in September 2014. The two units continue serving unique clientele and missions, as well as cooperating closely in a number of areas.

Information Transfer Plan

Basic Information

Title:	Information Transfer Plan
Project Number:	2016NE289B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	1
Research Category:	Not Applicable
Focus Categories:	Education, None, None
Descriptors:	None
Principal Investigators:	Chittaranjan Ray, Steven W. Ress

Publications

There are no publications.

Other Print Resources (distributed free to clientele and public):

Brochures and pamphlets:

These are produced as needed to support Water Center programming and activities. They include, but are not limited to, mission and programming of the Nebraska Water Center, NU Water Sciences Laboratory, annual Water and Natural Resources Tour and for other programs affiliated with or sponsored by the Nebraska Water Center. All are posted online, as online PDFs as well.

Water Center fact sheets:

Generally two pages, front-to-back, full color, produced as needed. Used to inform and promote general mission areas, or for specific programs, seminars, conferences, tour, etc.

Electronic Resources:

Nebraska Water Center:

<http://watercenter.unl.edu/>

Water Sciences Laboratory:

<http://waterscience.unl.edu>

Facebook:

<facebook.com/NebraskaWaterCenter>

Twitter:

<twitter.com/NebrWaterCenter>

YouTube:

<Youtube.com/NebraskaWaterCenter>

Conferences, Seminars, Tours, Workshops, Other Outreach:

Water and Natural Resources Seminars:

An annual series of seven or eight free lectures conducted roughly every other week from January to April. The series dates to the early 1970's. It covers a broad range of water and natural resource-related topics and is often themed to a particular area of research or interest. Individual lectures attract a broad public audience of 60 to 100. Normally 20-25 students enroll in the seminar as a one credit hour course, offered through the University of Nebraska-Lincoln's School of Natural Resources. News releases, Internet and social media postings support the lectures. Most lectures are taped and posted online at the Nebraska Water Center's YouTube account for public viewing.

Water and Natural Resources Tour:

The tour is in its 45th year, dating to UNL Extension "Irrigation tours" first conducted in the early 1970's. The 2016 tour traveled to the Denver, Colo. metropolitan area and Rocky Mountains to examine issues in the Platte River basin that ultimately effect downstream flows of the river into Nebraska. Among these issues is the growing Denver metro. urban areas, growing industry and

growth of recreation that all places increasing demands on basin waters. Tour attendees include state legislators, congressional staff, faculty, students, agricultural producers and water-related professionals. Young water professionals in the Nebraska State Irrigation Association's "Water Leaders Academy" are encouraged to attend through offer of a reduced registration rate. Sponsorships and registration fees pay all tour expenses. The event is jointly sponsored with The Central Nebraska Public Power and Irrigation District, UNL's Institute of Agriculture and Natural Resources and Robert B. Daugherty Water for Food Global Institute.

Water Law Conference:

This one-day event is planned and co-sponsored by the University of Nebraska College of Law. It focuses on current Nebraska water law in such areas as water right transfers, drainage issues, Clean Water Act enforcement, etc. and is primarily used as an annual updating of Nebraska water law primarily for practicing attorneys and water professionals, but is open to all. Continuing Legal Education (CLEs) credits are typically available in Nebraska, Iowa and Colorado. The event was last held in October 2016 and will be held again in October 2017. It generally attracts 150 to 200 participants.

Water Symposium:

The annual water symposium is a one-day event preceding the water law conference that themes on Nebraska water issues of current importance. Both panel discussions and individual speakers are featured. The event is co-sponsored by UNL's Institute of Agriculture and Natural Resources, The Robert B. Daugherty Water for Food Global Institute and the USGS Nebraska Water Science Center. The event was last held in October 2016 and will be held again in October 2017.

Faculty Mentoring:

The Nebraska Water Center helps mentor new water faculty, as well as graduate students and post-doctoral researchers, to help them establish successful careers. Newer faculty from the many academic units within the University of Nebraska, particularly those doing water-related research, teaching or outreach work, can attend Nebraska Water Center-sponsored brown bag sessions during the year where they get acquainted and receive advice from senior faculty and external partners on topics such as working with stakeholders, multidisciplinary research, and managing large data sets over their careers. In addition to helping link individual faculty members to groups, Nebraska Water Center faculty and staff meet with faculty individually as needed on an ongoing basis.

Research faculty retreats, for all University of Nebraska water-related faculty, are held typically twice per year to facilitate interdisciplinary cooperation for the purposes of grant writing and research collaborations. These retreats have been notably successful in getting faculty to work together on successful grant applications. These retreats have been held at NU campuses statewide and attendance has grown to oftentimes up to 100 faculty in attendance.

International OECD Workshop:

In September 2016, water researchers from around the world gathered in Lincoln for a three-day "Virtual Water in Agricultural Products: Quantification, Limitations and Trade Policy" workshop with financial support coming from the Organization Economic Cooperation and Development (OECD) as well as the Nebraska Water Center, Daugherty Water for Food Global Institute and UNL's Institute of Agriculture and Natural Resources. This international

research collaboration workshop was among the first of its kind at the University of Nebraska-Lincoln and will undoubtedly become a springboard for future events of a similar nature.

Other Outreach:

Nebraska Water Center staff routinely provides talks for groups and responds to requests for information. These include requests for water-related presentations from the public schools, the media, non-profit organizations, government organizations dealing with water issues and many others.

The Water Sciences Laboratory, established in 1990, is part of the Nebraska Water Center. It is a unique, state of the art analytical laboratory focused on teaching student researchers and developing new methodologies for the detection of trace contaminants such as explosives; pesticides and their metabolites; pharmaceuticals; steroid hormones in water, tissues, sediments and wastewater; cyanotoxins in lake environments; and new tools for isotope fingerprinting and geochemical tracers. Publicity, media relations, Internet visibility, marketing and other communications requirements of the laboratory are handled by the Nebraska Water Center.

The University of Nebraska-Lincoln's Pesticide Safety Education Office, tasked with educating licensed pesticide applicators on proper use of restricted and non-restricted use pesticides of all types, also relies on the Nebraska Water Center for much of its media support, as well as helping publicize a statewide series of educational seminars for applicators preparing to take state license examinations. The unit has no dedicated communications staff. Due to its essential water quality-related mission, the Nebraska Water Center helps fulfill those needs.

Educational Displays:

The Nebraska Water Center makes public exhibits in association with conferences, symposiums, trade shows, educational open houses and water and environmental education festivals. Nebraska Water Center staff make presentations and sit on steering committees for such annual educational and informational festivals as "Earth Wellness Festival" and others. For the past 10 years, the Nebraska Water Center's communicator has led UNL research and Nebraska Extension exhibits at Penton Industries' "Husker Harvest Days," the nation's largest irrigated farm exposition, which has more than 600 commercial exhibitors. During the three-day agricultural show, more than 25,000 attendees typically tour UNL research and Nebraska Extension exhibits.

Primary Information Dissemination Clientele:

U.S. Department of Agriculture
U.S. Environmental Protection Agency
U.S. Geological Survey
U.S. Bureau of Reclamation
U.S. Army Corps of Engineers
U.S. Bureau of Land Management
Nebraska Department of Natural Resources
Nebraska Department of Agriculture
Nebraska Health and Human Services System
Nebraska Department of Environmental Quality
Nebraska Environmental Trust Fund
Nebraska Association of Resources Districts (and 23 individual NRDs)
Nebraska Congressional delegation

Nebraska State Senators
Public and private power and irrigation districts
The Audubon Society
The Nature Conservancy
Nebraska Alliance for Environmental Education
Nebraska Earth Science Education Network
Other state Water Resources Research Institutes
University and college researchers and educators
NU students Public and parochial science teachers
Farmers
Irrigators
Irrigation districts and ditch companies
Private citizens

Cooperating Entities:

In addition to primary support from the USGS, the following agencies and entities have helped fund communications activities by the UNL Water Center during the past year.

U.S. Environmental Protection Agency
U.S. Department of Agriculture
Nebraska Department of Environmental Quality
Nebraska Research Initiative
Nebraska Game and Parks Commission
Nebraska Environmental Trust
Nebraska Department of Environmental Quality
National Water Research Institute
Nebraska Public Power District
Central Nebraska Public Power and Irrigation District
Farm Credit Services of America
Kearney Area Chamber of Commerce
Nebraska Association of Resources Districts
UNL Institute of Agriculture and Natural Resources
UNL Agricultural Research Division
UNL College of Agricultural Sciences and Natural Resources
UNL School of Natural Resources
University of Nebraska Robert B. Daugherty Water for Food Institute
NU College of Law
USGS Nebraska Water Science Center
Nebraska Center for Energy Sciences Research
Nebraska Water Balance Alliance

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	1	3	0	0	4
Masters	2	0	0	0	2
Ph.D.	0	3	0	0	3
Post-Doc.	0	1	0	0	1
Total	3	7	0	0	10

Notable Awards and Achievements